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A REVIEW OF THE TECHNICAL ASPECTS OF USING WIRE ROPES FOR HOISTING IN MINES

Prepared for
Occupational Health and Safety Branch
ONTARIO MINISTRY OF LABOUR

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Executive Summary

In early March, 2000, CANMET was engaged by the Ontario Ministry of Labour to conduct a study of the practices, in several key mining jurisdictions, of determining the criteria that are used to decide when the wire ropes used in mine hoisting are to be retired from service. After consultations with key experts in North America, Europe, and Africa, and reviewing information from Australia and elsewhere, the report was to include the criteria that are presently used, together with the levels of confidence that people place in these as well as the records of successes and failures - wherever such information might be available.

During the period 2000 03 27 – 2000 06 02, the writer travelled in Canada, the United States of America, the Republic of South Africa, the United Kingdom, Germany and Poland. Additionally, material from the Australian province of New South Wales, was made available through a document which had been conveyed to the Ontario Ministry of Labour. Information on practices in Hungary was also accessed through a report on which the writer had collaborated in 1988.

The first sections of the report present a summary of the history of wire rope and trends in manufacturing technology. It is noted that these vary greatly between the industrialized countries visited, with very high standard for both the manufacture of the wire and the final wire rope in place in South Africa, and lesser standards elsewhere. In the writer's opinion there is room for the development of such standards in Canada. It is noted that wire rope is a complicated machine which is susceptible to damage from a variety of causes. This latter point is covered in a later section on the wear and deterioration of wire rope.

In the first sections there is also a general review of both the state of the mining industry and the mine hoisting practices in the countries visited. In general, the mining industry is in a state of rapid decline in Europe – the principal cause being that it is more economical to purchase coal from offshore than it is to mine it under local conditions. The high state of mechanization of mines in South Africa and North America was noted as causing the rapid decline of the European coal industry. This is having a major social impact, with unemployment as great as 20% being forecast for Poland.

In terms of hoisting, the mines in Europe are generally less than 1000 metres in depth. This has led to ideal conditions for friction hoisting, with the result that this type, normally ground mounted, prevails. Many of the installations are "old", with many single rope friction hoists.

In both Canada, the United States, and South Africa, however, drum hoists are the norm. While there are but "a handful" of mines deeper than 5000 feet in the United States, there are many in Canada, and a great many in South Africa. The trend in South Africa is towards "ultra-deep" mines for which the access will be through single-lift shafts. During the visit, the writer had the opportunity to visit the South deep development, at which the shaft was at 8900 feet on the day of the visit (very close to the planned ultimate depth of slightly over 9000 feet).

Following this, the reader will find a section on the requirements as regards the safety factors used in the various countries. In general, the safety factors used in Europe are much higher than those used in either North America or South Africa. Historically, it was observed that these

originated in the days when steam-powered hoists were common, and when hoisting practices were much rougher than at present. Because the depths of mines are relatively shallow there have been no pressures from mine operators to reduce these. The result is safety factors which are very conservative by either North American or South African Standards.

Concurrently, in South Africa, new Codes of Practice are being implemented, which, if followed, will result in much deeper shafts and more sophisticated hoisting plants. In order to take advantage of the Codes of Practice, however, mine operators will be obliged to virtually eliminate the dynamic stresses which can effectively reduce the normally-permitted safety factors whilst either loading skips or operating the hoists (such as during acceleration, deceleration, emergency braking). The conditions are clear: single lift shafts can become deeper if, and only if, mine operators follow much-improved hoisting and monitoring practices. With the reduced margins, there is little room for error. The obligations upon operators are clear. The writer visualizes that these trends will become attractive elsewhere and that similar pressures will be brought to bear on Canadian regulators.

Next, a review is made of the players and the practices that are followed in the key jurisdictions. Summaries are made of the inspection practices required – the key point being that all of the means of assessment that are presently available are used to make a complete evaluation of the state of a wire rope. While the criteria used to determine if a rope should be rejected vary slightly from place to place, all believed that we need all of the tools that are available to us. In brief, these are: (1) visual examinations; (2) destructive tests; and (3) non-destructive tests. There is simply no substitute for any of these.

Visual inspections, on frequencies which vary from daily, before the beginning of hoisting, to those which accompany non-destructive tests are considered to be absolutely essential. In Canada and the United States there were feelings that insufficient attention is now paid to daily inspections and that standards have declined. These examinations provide a daily assessment as to whether or not a rope has been damaged. There is a clear need to improve practices.

Destructive tests of rope samples are required in Canada and South Africa and are replaced by aggregate testing in parts of Europe (in which the theoretical strength of a rope is the aggregate of breaking tests on samples of the wires used in the construction). All of those interviewed stated that strength testing is essential if one is to know the strength of a rope at installation and to track its performance thereafter. Aggregate testing is considered by many to be a less-accurate substitute for assessing the strength of a rope, but, it is to be noted that, in the countries where this is the practice, the safety factors used to design mine hoisting plants are more conservative. Thus, the higher factors of safety probably compensate for any small inaccuracies in estimating strengths. It is to be noted that this situation can not occur when the factors are reduced to accommodate deeper mining operations.

Non-destructive tests are equally irreplaceable since these provide the only means available of having some indications of the conditions within a rope. Throughout the visits, it was clear that there are needs for improvements in: instrumentation technology; the ways in which instruments are qualified, calibrated, and operated; and in the training of instrument operators and wire rope inspectors. South Africa is at one end of this spectrum, through the conditions and

qualifications described in their new Codes of Practice. North America is at the other extreme. The training of wire rope inspectors is described in greater detail in a later section of the report.

It is to be noted that non-destructive testing methods become about the only possibility when one considers the design of the advanced continuous monitoring systems which will be required in the future. This, in its own right, should be a substantial incentive to the development of improved non-destructive test systems.

Also in the report, the reader will find a lengthy section in which are detailed the rope retirement criteria that are used in the several jurisdictions. Many differences will be noted, and particularly as regards the criteria which are based on the number and distributions of broken wires per specified lengths of rope samples.

Equally, it has been observed that, up until the present, the regulations have effectively been written as if all rope constructions were equal. That there are significant differences between different constructions can be demonstrated by the fact that NDT methods are of little use as regards the inspection of locked-coil ropes. This was stated as being the reason that six-stranded ropes continue to be used in the deepest South African operations.

Thus, it is welcome development that separate criteria, based on rope constructions, are being introduced in South Africa. This has also been strongly advocated in the United States, and should stimulate similar developments in Canada.

Finally, in a look into the future, the writer outlines the developments that could take place in both hoisting and rope inspection practices in Canada. The view is that both the Codes of Practice of South Africa and the Guidelines for Safe Mining of the Australian province of New South Wales are admirable documents and should be useful as role models for Canada.

1.0 Introduction

In any underground mine for which a shaft provides access to the workings the wire hoisting rope is the lifeline of the operation. On its sinewy steel strands hangs the safety of miners as they are lowered and hoisted from their working places. With it are lowered the equipment and supplies, and are hoisted the mineral products which sustain the enterprise. Without a hoisting rope operations can not continue.

For these reasons the design of mine hoisting plants and wire hoisting ropes have been extremely conservative. Practice demands this since shaft accidents, in addition to often being ghastly, will shut down an operation for a period. To say that rope failures are to be avoided at all costs is an understatement.

Thus, through the years, the mining regulatory authorities around the world have established design guidelines, safety factors, and codes of practice for mine hoisting plants. The safety factors have resulted from the experiences of the years and represent the best estimates of values necessary to avoid failures at critical points, while, at the same time, not effectively prohibiting the use of wire ropes. As shafts are sunk to greater and greater depths the sizes of the hoisting ropes needed increase - until the point is reached that the applicable safety factors and the capabilities of manufacturers to wind ropes of large diameters precludes even larger sizes and, consequently, the design of deeper shafts. At this point pressures from mine operators could begin to develop for authorized variances from proscribed practices to permit lower safety factors.

The original strength on which the design is conceived is not the only consideration, however. Occasional manufacturing defects, objects striking the ropes in the shaft, corrosive mine waters, and the wear and tear of repetitive and frequent use are but some of the ways in which the strength of a wire rope can be reduced from the expectations of the mine operator.

Thus, it must be expected that wire hoisting ropes will deteriorate with time after which they are installed for service. The key questions are twofold. First, how long will the rope be usable until replacement becomes necessary? Secondly, how can this point in time be determined with confidence, in the full knowledge that by extending the demands placed upon a rope beyond some critical point the likelihood of a failure increases greatly. There can be no margin of error.

Through the years, then, several practices have evolved through which the conditions of wire ropes in shafts can be assessed and compared with the criteria which have been developed to indicate when replacement becomes mandatory. In the first instance, visual inspections are used to assess the ropes appearance and to indicate if there are reasons why its remaining strength may be suspect. Broken wires, or strands, nicks and cuts from objects which have struck it, excessive corrosion, excessive wear or wear that is irregularly distributed, and lack of lubrication are all indications that the condition of the rope has probably deteriorated.

Secondly, physical breaking strength tests on samples from accessible points, the ends, are used to determine if the strength of the rope has decreased. The resulting figure is known as "Loss of

Breaking Strength", or "LBS". As the result of generations of worldwide practice criteria have been developed to indicate when the loss of strength is such that the rope must be discarded.

Third, parallel with physical testing a number of non-destructive testing techniques have also evolved. Without exception, these involve passing the rope through a magnetic field and recording the variations in the flux which are detected. Experience has shown that irregularities can be correlated with damaged sections, strands, or individual wires. From these, criteria have been developed through which it can be decided to scrap a rope if there are too many broken wires in a set length or if the rope has lost too-much cross-section area through repetitive wear. The latter is known as "Loss of Metallic Area", or "LMA".

Finally, and fourth, some operators or jurisdictions have decided that ropes should be replaced either after a certain period of service or after a stipulated cumulative tonnage has been hoisted. These criteria are based entirely upon judgement and practice.

None of the techniques or criteria, however, are foolproof. The problems of visual inspections are that these may not be sufficiently frequent, or may be too cursory because of lack of attention by the inspector. One also can not look into the core of the rope and assess the condition of its interior.

Physical tests, while being more representative of the condition of a sample of rope, however, may not be indicative of the integrity of the entire rope. Because it is out of the question to cut out a sample and then splice the rope, the practical considerations demand that samples can only be obtained from either the end at which it is attached to the skip or conveyance (sometimes called the "Shackle") or the end at which it passes into the drum of the hoist (called the "hawse hole"). These may or may not be the points at which the rope has been most damaged, thus introducing the argument that the criteria used to scrap a rope may not be sufficiently conservative.

Next, non-destructive tests are extremely judgmental and are not completely foolproof. Defects may not be adequately detected for a variety of reasons, while the skill and experience of the operator are of critical importance. Next, the instruments must be properly calibrated and the ropes passed through it at a reasonable speed. Simply stated, the results from an improperly calibrated or inaccurate instrument in the hands of an untrained and careless operator can be extremely dangerous.

Finally, the criteria that a rope should be replaced either after a certain period or a certain service life are entirely empirical. In fairness, however, these may be much more conservative than would be used through other approaches. After all, no responsible operator or authority would countenance a practice which might result in a failure.

Against this background, a key issue in the year 2000 is the direction in which future practices and criteria should proceed. Have we reached the point when global practices can be combined in establishing universally acceptable inspection methods and the criteria by which ropes can be either passed or failed? Are testing methods sufficiently developed that we can decide on which are essential and which are optional? Can the criteria against which the strengths of ropes are

determined be improved? Next, in what direction should we proceed as mining operations progress to even greater depths and the pressures develop to permit deeper shafts through reduced safety factors. And finally, can all of these be brought together into a protocol and a code of practice which reflects both the art and science which is at our disposal as we move into the 21st Century?

These questions have been at the forefront of the thinking of both specialists and regulators around the world. What is the present thinking on the criteria that are used to determine whether or not a wire hoisting rope should be scrapped? How successful have these been? How confident are we in the value of their continuing use? Have there been conspicuous successes and failures? What should the future bring?

With that in mind, CANMET and this writer were commissioned by the Ministry of Labour of the Province of Ontario to discuss these issues in several of the mining nations which are known for their expertise in wire rope technology and to report on their views on these issues.

For the first part of the study the writer concentrated on interviewing key persons in those major mining nations in which the practices are the most similar and relevant to those in Canada. In addition to discussions in Canada, these included: the United States of America; the Republic of South Africa; the United Kingdom; Germany, and Poland.

Subsequently, other information was provided either from previous experience (Hungary, in Geller et al.) or from information that had been provided to the Ontario Ministry of Labour (New South Wales, Australia).

2. The History of Wire Ropes

Twisted or plaited ropes made from strips of hides or fibres of natural materials were probably known as early as Palaeolithic or Neolithic times. By the Egyptian 4th Dynasty (3500 BC) the art of rope making had advanced to the point that large ropes were used to haul the huge stones used in the construction of the pyramids.

Drawn wire has been in use by mankind for about 4000 years. During the second millennium BC the ancient Egyptians were reported to have produced gold thread by hammering beaten gold rods through holes in stones (Aitchison, p. 213). Cables of wire rope, about 8.3 mm in diameter and 4.5 m long, and consisting of three twists of bronze wire, each containing fifteen strands, were in use by the Romans and were excavated from the ruins of Pompeii (Aitchison, p. 214). By the 16th Century both copper and brass were being drawn into wire throughout Europe (Aitchison, pp. 395-396).

Iron, used in chain mail in Roman armour, has been fabricated into wire for at least 2000 years. When the modern technology of drawing the metal into long coils of wire was developed is not clear, but it was probably about the 10th Century, during the fabrication of chain mail in Europe. Dutrizac, in a conversation with the writer, reported that steel wire was also made, albeit accidentally, at the same time (Dutrizac, 2000 03 21). Wire rope, of strands of iron, seems to have been introduced for the construction of footbridges about 1810-1820. During the late 18th Century (about 1770) there were reported to have been about 12 mine shafts in Europe that were deeper than 1000 feet (Delorme). Both hemp rope and wrought iron chains were used for hoisting. The former, however, rotted easily, while the latter was cumbersome.

Originally, wire rope was made as a "selvage" - a bundle of long parallel wires that were bound together and covered with tarred hemp yarns (Encyclopædia Britannica, pp. 15:1147 et seq.). While useful for supporting bridges, however, the cables were too stiff to withstand the bending stresses associated with hoisting service.

The person credited with the invention of the predecessor of modern wire rope, William Albert, was a mining official in the Clausthal region of Saxony. His rope, developed during the period 1831-1834, and made of twisted strands of iron, proved to be so superior to the hemp rope that was in use at the time that it was adopted quickly into widespread use. The form of construction, known as the *"Albert Lay"*, was introduced into England in 1839 (Encyclopædia Britannica: pp. 15:1147 et seq.).

In North America, John Augustus Roebling, the designer of many well-known suspension bridges in the mid-19th Century, is credited with having been the first to manufacture stranded wire rope.

The John A. Roebling's Sons Company, once a major manufacturer of wire rope in the United States of America, fell upon hard times, however, and ceased operations in the 1950s. Among their famous early bridges were: the Penn Canal aqueduct across the Allegheny River, Pittsburgh, Pennsylvania (1844-1845); the span across the Niagara gorge linking the New York Central and Great Western Railway of Canada (1851-1855); the Brooklyn Bridge, across the

East River, New York City (1869-1883). The latter was reported as being the first use in bridge construction of cables of Bessemer grade steel, with a tensile breaking strength of 190,000 pounds per square inch. This represented a significant improvement from the iron wires of the past.

In essence, the wire hoisting rope is the lifeline of the underground mine with access through a shaft. Without a functioning hoist the mine comes to a standstill. It is not an exaggeration to state that the viability of the enterprise hangs on the integrity of the wire rope in the shaft.

In the life of a mining operation, shaft accidents are amongst the worst possible. A broken rope can result in the conveyance suspended from it plunging to the bottom of the shaft. If that conveyance is a cage with personnel on board it is a certainty that all will be killed. If the conveyance is a skip with a payload of ore in it the result will probably be tremendous damage to the shaft. In either case, terrible consequences will accrue to the mine operator.

During the past decades, as the prices of metals have remained at relatively low levels and as the costs of operation have increased, underground mining has changed from the expensive, highly-selective, methods of the past to the bulk mining methods of the present. As it has in almost every other industry, mass production has been introduced. The economies of scale simply can not be ignored.

As regards mining, the impacts on major companies have been focussing their efforts on the larger orebodies which are amenable to bulk mining. All of the physical characteristics of a mine have been enlarged - from the dimensions of the openings below ground to those of the shaft which provides the access.

In South Africa, where some 400,000 persons work underground daily (Zondi, 2000 04 18), mine hoisting plants have attained enormous dimensions. It is not uncommon for multi-level (decked) cages to transport up to 300 persons on a trip. Shaft accidents, when these occur, result in enormous damage and loss of life. During the visit to the Republic of South Africa the writer was privileged to have been able to visit not only some of the most extensive hoisting plants in the world (called "shaft banks"), but also the world's deepest single shaft and the most sophisticated hoisting plant, the former at the new South Deep mine and the latter at the Moab Knotsong mine (formerly Vaal Reefs Number 11 Shaft).

In Canada, notwithstanding the same trends to larger and more cost-effective mining operations, the record has been excellent. Following the accident at the Paymaster mines in 1945, when 16 were killed when a corroded hoisting rope broke, the regulations that we know today were introduced. It must be noted that not a single person has been killed in Canada in a cage accident since and that not a single hoisting rope has broken in Ontario in the past ten years. Canadian practice as regards wire ropes has been very conservative. This has had the desired effects on the safety of mine hoisting plants. It was noted in the writer's discussions that, in Ontario, some 20 ropes are rejected each year as the result of destructive testing (OMOL).

3. Development of the Manufacturing Art

Wire ropes are very complex structures. First, a number of individual wires are twisted as a helix around a core to form a strand. Then, several strands, normally six, are twisted as a helix in the opposite direction about a larger core so as to form the rope. The reason for twisting the strands and the final rope in the opposite direction is to impart a torsional balance to resist the tendency of a wound rope to unwind. Nonetheless, the structure is so complex that it is not possible to determine exactly how the load is being shared at any particular point in the rope.

The cores of ropes for mine hoisting may be natural fibres, such as sisal or hemp, polypropylene monofilament fibres, nylons, other plastics, or wires. The purpose of the core is to ensure a firm structure and a foundation for the positioning of the wires and to provide for some means of lubrication.

In some constructions the wire rope core is an independent wire rope with its own core. These cores are designated as *IWRC*, or, *Independent Wire Rope Core*. In others, the core is a *Wire Strand Structure*, or *WSC*, or *SC*, which is a strand of multiple wires. These latter are used only as utility cables.

Historically, *iron* (actually *low carbon steel*), with a tensile strength of about 100,000 psi, was used for wire ropes. It is still used for guy wires, tillers, and sash ropes but has been replaced in hoisting applications by higher grades. Of these, *Traction Steel*, with a tensile strength of from 180,000 to 190,000 psi, and with high resistance to fatigue by bending, is often used in elevators.

Most commercial wire rope is manufactured from one of the *Plow Steels*. In ascending strengths, these are: *Mild Plow Steel*, *Plow Steel* (about 225,000 psi.), *Improved Plow Steel*, and *Extra Improved Plow Steel*. Improved Plow Steel, the most-often used, is a high-carbon steel with a tensile strength of about 260,000 psi. Above this in grade is *Extra Improved Plow Steel*, with tensile strengths of from 280,000 psi. to 340,000 psi. This grade was developed for the higher safety factors that can be obtained and also for greater resistance to abrasive wear.

During the 1980s, as mines in South Africa were developed to greater depths, manufacturers began to use Ultra High Tensile strength steel (2300 Mpa) in order to produce stronger ropes. It was noted (Chaplin, 2000 05 25) that the initial experiences were favourable but that, thereafter, rapid losses in strength became evident. This deterioration with time was apparently due to the increased possibilities of interstrand nicking (and loss of strength) in ropes which involved many more wires, and wire contacts. This has been mentioned by several people as being the principal problem to be anticipated when using stranded ropes.

For the most part uncoated, or *bright*, wires of high-carbon steels are used. In those conditions when maximum resistance to corrosion is required, however, there are two alternatives. The first of these is to use *galvanized wires*, with a tensile strength about 10% less than for the corresponding grades of carbon steel. A second alternative is to use a *phosphor bronze* alloy, with a strength about equal to low carbon steel.

Ultimately, in the selection of a wire rope for hoisting, a number of trade-offs must be considered. First, a larger number of smaller wires for any given diameter of rope will result in greater flexibility but in less resistance to surface wear and abrasion. Second, from the opposite perspective, a smaller number of larger wires, while being more resistant to abrasion will be less flexible and more susceptible to bending fatigue. As a general rule, one can not obtain increased resistance to both fatigue and abrasion.

4. Rope Constructions and Where These are Used

Today, wire ropes for mining include six-, eight-, and nine-strand constructions, multi-strand non-rotating (or non-spin) ropes, compact Ultra High Performance, or UHP™ ropes (Haggie Rand), and ropes of flattened (or triangular) strands. In addition to these, however, there are so many different constructions that describing all of these can become very confusing.

Nonetheless, most ropes are classified by numbers which describe the number of strands and the number of wires in each strand. Thus, a 6X19 rope is constructed of six strands of nineteen wires per strand. The second number, however, may be nominal and may also be used to describe ropes in which the number of wires in each strand is slightly more or less than the numerical descriptor. As an example, 6X37 ropes may contain from 27 to 49 wires per strand. Additionally, if a wire core is used a second group of numbers may be used to describe the construction of the wire core, such as 1X25, i.e. a single strand of 25 wires.

Wire ropes are constructed in several different arrangements in which the wires and strands of wires are wound helically about their respective central cores. The term "*lay*" is used to describe the direction in which both the wires and strands are twisted. When looking along a rope, if the strands go away to the right, the lay is described as "*right lay*". "*Left lay*" indicates that the strands go away to the left.

In "*regular lay*", the wires in each strand lie in the opposite direction to the lay of the strands. This is done to provide a torsional balance and to resist the tendency of a rope to unwind. A regular lay rope, in addition to being more stable, is also more resistant to crushing than a Lang lay rope. In "*Lang lay*", both the wires in the strands and the strands lie in the same direction. Lang lay rope, while being more resistant to both fatigue and abrasion is prone to rotation.

The term "lay" is also used to indicate the length along the rope in which a strand makes a complete spiral around the core. This has an important application in rope inspection since one criterion for removal is based on the number of broken wires that can be detected in one lay length.

During the author's visits, an observation was made that the lay length of a wire rope should be verified at several points immediately after its installation. This is often neglected, but can be a critical point since the lay length of the rope as manufactured may be slightly different than the lay length given in the design specifications for the construction (i.e., the nominal lay length). The reason given (Chaplin 2000 05 25) was that manufacturers often produce ropes that are about 5% greater in lay length than the nominal values listed. On the surface, this may seem to be a small point. It is crucial, however, when considering that calculated extensions in lay length are also a basis for the rejection of ropes.

Referring to rope constructions, the first standard construction is known as *Coarse Laid* rope. Designated as 6X7, it comprises ropes with six strands of seven wires each. The strands are each laid with one layer of wires around the centre wire. Right regular lay is normal, but Lang lay is also available. For any given diameter of finished rope the construction involves the smallest

number of wires. Thus, while having the maximum resistance to abrasion and crushing, the rope has limited flexibility and is less resistant to fatigue. Normally, the cores of such ropes may be fibre (FC), independent wire rope (IWRC), or wire strand (WC). While useful for heavy hauling, large sheaves and drums are required to accommodate this rope.

The next type of construction, also made of six strands, is known as "*flexible*" or "*standard hoisting rope*". Within this grouping, there may be as few as nine wires per strand, or as many as 26. Both regular and Lang lay are available, with several constructions being known. The first of these, the "*Seale*" group, are manufactured by laying two concentric layers of wires around the centre wire of each strand. The second, known as the "*Special Seale*" of "*Filler Wire*" group, ranging from 6X16 to 6X37, are made by laying two or three concentric layers of wires around each centre wire, and filling the voids between the outer two layers with smaller spacer wires. The cores may be fibre (FC), independent wire rope (IWRC), or wire strand (WC). In a third construction, known as "*Warrington*", two sizes of wires comprise the outer layer which is laid on one layer of equally-sized wires laid around a centre wire. Further variations with round wire are known as: "*Seale Filler Wire*"; "*Filler Wire Seale*"; "*Warrington Seale*"; "*Seale Warrington Seale*"; and "*Roebling Special Seale*". All are assembled with the view of increasing flexibility. It is to be noted, however, that all do not necessarily result in stronger wire rope. Further, the greater the flexibility the less the resistance to abrasion and crushing.

A further type of construction, known as "*extra flexible*" or "*extra flexible hoisting rope*", and nominally designated as 6X37, is made of six strands with from 27 to 49 wires in each strand.

At the risk of adding confusion, other six-strand constructions involve flattened strands (wires rolled to nearly triangular cross-sections). These include: 6X19(1/9/9) "*Seale Masterform*"; 6X26(1/5/5+5/10) "*Warrington-Seale Masterform*"; 6X31(1/6/6+6/12) "*Warrington-Seale Masterform*".

Modern ropes also include eight-strand ropes known as "*special flexible hoisting rope*". The 8X19 group is usually assembled around a fibre core with "*Seale*", "*Modified Seale*", "*Warrington*", and "*Roebling Special Seale*" constructions known. The smaller diameters are usually used for elevators. Other patterns include: 8X25 IWRC and 8X26 Fibre Core. While more flexible than six-strand ropes, the eight-strand ropes are not as strong because of the size of the fibre core and are less able to resist crushing.

Another construction involves wires which have been flattened into approximately triangular shape. The cross-section of each strand resembles an equilateral triangle with rounded corners. The 6X8 rope is formed by winding seven wires around a triangular centre wire ("*simple type*"), while the 6X30 Style G comprises two layers, each of 12 wires, laid around three pairs of wires to form a roughly triangular core ("*compound type*"). Such ropes, while more expensive to manufacture, are very resistant to crushing and abrasion. These are widely used as hoisting ropes in mines.

Next, *non-rotating or non-spin ropes* are constructed by laying ribbons of flattened wires around a hemp core in concentric layers. A type, known as 18X7 *Non-Rotating rope* is made by laying the inner layer of six strands and the outer layer of 12 strands in opposite directions.

Finally, the *Locked Coil* rope is perhaps the most complex of all rope constructions. In it, the outer layers consist of wires that have been rolled into an almost Z-shaped cross-section. When wound, the final rope presents an almost-smooth external surface which is very resistant to pressure (crushing) and abrasion. Beneath these outer layers, which may be as many as four, the inner core is made up of round wires. The result is a very high density of metal in the cross-sectional area of the rope (known as "*fill factor*") and a very high strength rope for any given diameter.

From the above it will be appreciated that a vast array of rope constructions are available to mine operators. The differences between these are so great that it can be argued that none of the criteria for rope retirement that are presently in use can be applied to them all with equal meaning. The loss of diameter criterion, for example, has vastly different implications if applied to both standard Seale and Locked Coil constructions (as it is). Since rope constructions have just been discussed in some depth, however, it is appropriate to introduce this thought at this time in order to introduce the concept that separate criteria may be required for each type of rope construction.

At present, some consideration is being given to hybrid ropes and those made of advanced fibres. An example of the former is Notroplast, a multi-stranded non-rotating metal rope with polyester between the wires in order to prevent cross-strand nicking. It was observed that the four layers that are used in its construction makes it difficult to test using electromagnetic methods (Falconbridge, 2000 03 28). Other ropes made entirely of advanced fibres are also impossible to monitor using EM methods. These include braided polyethylene ropes, which can withstand tremendous tensile forces and which are commonly used as marine towlines. A 3-in. diameter example that was seen at the National Institute for Occupational Safety and Health (NIOSH) (2000 04 04) was cited as having an ultimate tensile strength in the range of 300,000 to 400,000 pounds. Unfortunately, the rope creeps as much as 25%, then becomes brittle, and breaks.

In order to resist creep, a modified version with a non-yielding nylon core was tried. This, too, was unsuccessful as, when the load was released the nylon rebounded causing the yielding polyester to "birdcage".

Kevlar ropes with a Warrington inner construction encased in an outer layer of circular strands have also been considered as hoisting rope. While strong, the rope proved to be unable to withstand the forces of crushing as it was wound on the drum.

5. Modern Manufacturing Technology

The wires which comprise the strands of wire rope are produced by drawing wires through a die until the correct diameter has been achieved. As would be expected, the process results in the generation of considerable heat - to the point that the wires become extremely hot. Unfortunately, the generation of this heat and the subsequent lack of cooling of the wire can result in a change in the internal structure of the metal which is known as "strain aging". In essence, the wire becomes more brittle with time. The effect was noted as being more pronounced with the larger diameter wires. The somewhat paradoxical result, then, is that the combined strengths of two smaller cables could add up to exceed that of a single cable with the same total cross-sectional area!

During the visit to the United Kingdom, Professor Chaplin (2000 05 25) observed that the South Africans have largely overcome the problem of strain aging in wire ropes through introducing cooling at all stages during the manufacture of wire ropes and by placing the cooling as close as possible to the sources of the heat – i.e., beside the dies through which the wires are drawn and immediately after the points at which the wires are wound into strands and the strands into the final rope. He added that the process of galvanizing is also thought to generate heat which can accelerate the ageing process.

During the winding process, the wires are rotated and pulled into position against each other. As the result of this a certain amount of nicking of the strands ("interstrand nicking") occurs and the total strength of the combined wires of the rope is slightly reduced. These are known as "spinning losses". As mentioned previously, it is also to be noted that the lay length of ropes as manufactured must be expected to vary slightly from the nominal values for the constructions listed in manufacturer's catalogues.

Today, wire rope manufacturers may or may not extrude the wires which are used. At Wire Rope Industries, for example, it was understood that it is a common practice to obtain wire stock from a variety of manufacturers and to shop around the market for quality, price, and on-time delivery. At Haggie Steel Wire Ropes, in Johannesburg, however, it was noted that all of their steel is purchased from Ipsco, in Japan, and that rigorous quality control is maintained. Each coil of wire that it had drawn is tested for tensile strength and torsional resistance at both ends of the coil. It was noted that the plant is accredited at the ISO 9002 level, and also by the American Petroleum Institute (API), Lloyd's, the American Bureau of Shipping (ABS), and Veritas. Further, in South Africa, it is a requirement of the Minerals Act and Regulations that "Any winding rope must be manufactured by a manufacturer accredited in terms of ISO 9000: "Quality Systems - Model for quality assurance in design, development, production, installation and servicing" (16.20.1)".

Nonetheless, one problem in manufacturing can be that the quality of the products of the initial producers could have deleterious effects on the overall quality of the finished constructed wire rope. The staff of the Wire Rope Laboratory of the Ontario Ministry of Labour noted (2000 03 29) that, while poor cables are rare, a few come onto the market nonetheless. The result is that a few are rejected by them each year after the initial test.

The causes vary, but it was noted that the main problems relate to: a lack of ductility in the steel that was used; lack of quality control; and not all of the wires being the same. It was suggested that standards should be established regarding the manufacture of the steel wire used for wire ropes, and that the Canadian Standards Association (CSA) would be the appropriate body. It was noted that such standards do exist in the United States of America.

For many years stranded wire hoisting ropes were manufactured with hemp (sisal) cores. The hemp was used as both a foundation for the strands and as a source of lubricant for the core. In recent years, however, hemp has been replaced in Canada by nylon, and then polyester. Almost immediately after the introduction of nylon cores it was noticed that the wire ropes were deteriorating faster than before. The problem was ultimately traced to the steam that was used as an agent to stabilize the nylon. Manufacturing of the final wire rope, if it took place immediately afterwards, resulted in moisture (and, more exactly, water), being locked into the rope). At first, the problem was hidden by the field dressings that were used since these locked the moisture inside the ropes. After the signing of the "Montreal Accord", however, some of these environmentally-unfriendly dressings were eliminated, most specifically 111 Trichlorethane. The effect of the change of dressings was that water was then seen to be dripping from the ropes and the cause of the corrosion causing the reduced service life was identified. The immediate result was that users noted a rapid reduction in the service lives of their ropes. INCO (2000 03 28) mentioned that ropes which had previously lasted from 30 to 40 months suddenly lasted about 12 months. INCO immediately ceased using any wire ropes with nylon cores and the industry followed. Today, only polyester cores are available in Canada. In South Africa, however, sisal cores continue to be used. The writer witnessed a part of the manufacture of one such rope (2000 04 17).

During the author's visits in South Africa it was also mentioned that the replacement of sisal cores with polypropylene had once resulted in "cup-hooks" (or slack strands, or birdcaging) in some ropes (Zondi, 2000 04 18).

An interesting aspect of manufacturing practice in South Africa is that manufacturers of wire rope are required to have a quality-control system in place at the plant. Standards particular to the manufacture of wire rope do not yet exist but it is thought that this will happen at some time.

6. Mine Hoisting in Canada, the United States of America, South Africa, the United Kingdom, Germany, and Poland

In Canada, it has been estimated by Delorme that there are 43 friction hoists and up to 300 drum hoists in operation. The former represents a reduction from the 68 that were in use prior to recent mine closures, while the latter is a rough estimate of the number installed but not necessarily in use (the latter figure is probably in the 200 to 230 range). In Canada, there are several shafts that exceed 3000 feet in depth and a number that are, and will be developed as, deep operations. About 30,000 persons are employed in Canadian mining. In recent years the fatality rate has hovered around 15 to 20 persons per annum. It is significant that there has not been a fatality in a shaft accident in Ontario during the past ten years.

In Canada, mining is the responsibility of the provincial and territorial governments. Each enact their own mining and health and safety legislation and each are responsible for mines inspections. In general, there are regulations relating to the design and operation of hoisting plants, the use and inspection of wire ropes, retirement criteria for the same, and the means by which rope quality and soundness are assessed. There are virtually no exemptions, with all shafts and ropes being covered by the regulations.

Meanwhile, in the United States of America, the comparable numbers of friction and drum hoists have been estimated at 35 and 500, respectively. It is to be noted, however, that 400 of the latter are small installations and that only 100 of the drum hoists are considered to be "significant". According to officials at MSHA, the great majority of shafts are less than 1000 feet deep, with only a handful sufficiently deep to be classified as deep mines (i.e. over 3000 feet). It was mentioned that the fatality rate in American mining has been fluctuating at about 80 per annum, with no decrease taking place. Many American operations are small coal mines, in which hoisting is in inclined shafts, or "slopes". It was noted that, typically, slope ropes last from six to nine months while shaft ropes last from five to six years. During the conversation with MSHA officials it was said that there had not been "a serious hoisting accident in a long time" (2000 04 03).

In the United States of America, mines inspection is regulated through the Mining Safety and Health Administration, MSHA, of the United States Department of Labor (sic). A significant difference from Canadian practice is that there are no regulations at all concerning wire ropes in shafts which are not used to hoist personnel – i.e., Production, or "rock" shafts. The Regulations apply "to those hoists and appurtenances used for hoisting persons. However, where persons may be endangered by hoists and appurtenances used solely for handling ore, rock, and materials, the appropriate standards should be applied" [57.19000 (a)]. In simple words, there are no regulations in place in respect of safety factors, rope retirement criteria, or means of assessment in non-personnel shafts. Further, persons who ride in production hoists occasionally, in order to make inspections, are exempted from the regulations.

South Africa's mining industry is colossal. Even though it has suffered through the closures of major no-longer-viable gold mines in recent years, the fact is that over 400,000 persons work underground every day in the Republic. This is at least ten times the comparable numbers in the Canadian mining industry. During the author's visit it was noted that some 4,000 kilometres of

wire ropes are in active use today in underground South African mines. This could be compared with the 40 kilometres of ropes used in the nickel/copper mines of the Sudbury basin. At present, it was mentioned that there are 21 friction hoists and about 700 drums hoists in operation in the Republic of South Africa. A great many of the country's operations in South Africa can be classified as deep mines and several would be rated as very deep - with the depths of the operations exceeding 10,000 feet.

While drum hoist installations are similar around the world (and are usually based on parallel double drums, or bi-cylindro-conical drums, or Blair hoists), it is to be noted that all Canadian installations of friction hoists are in towers while the practice elsewhere is ground-mounting. In part, the reason for this Canadian practice is that it is practical to mount the larger hoists directly over the shaft - thereby eliminating the sheaves that are necessitated through ground-mounted installations. Deflection sheaves, to bring the ropes into alignment with the centres of the compartments, are necessary, however.

Regardless of the style of mounting, the constraints upon designs are such that friction hoists can only be used in shafts that are up to about 6000 feet deep. One of the deepest of such installations in the world, in fact, is at Nerco's Con mine, at Yellowknife, in the Northwest Territories. In this instance, the loading pocket is 6230 feet below the surface. Falconbridge's Kidd Number 4 shaft, near Timmins, Ontario, at 6200 feet, is also noteworthy.

Conventional drum hoists, on the other hand, are presently limited by design constraints to about 7500 feet. It is to be noted that North American practice in this respect compares very favourably with that in South Africa. While the latter has many more deep shafts than there are in North America, the level of technology is similar. In Canada, INCO's Creighton Number 9 shaft, at Lively, Ontario, at 7150 feet, was, until recently the deepest single-lift shaft in the country. It has since been surpassed by: Kinross Gold's Number 4 shaft, at 7400 feet; Agnico-Eagle's Laronde shaft, at 7450 feet. In the planning stages are INCO's Victor shaft, near Sudbury, at 7950 feet, and Falconbridge's Onaping Deep shaft, near Onaping, Ontario, at 8700 feet. The Victor shaft had already been sunk to about 4500 feet in 1999 when the work was suspended for financial reasons (depressed metals prices).

The latter will feature a Blair (BMR) hoist, the first major installation of its kind in Canada, but common in South Africa. With two hoisting ropes attached to each conveyance, the Blair (BMR) hoist designs feature two smaller ropes rather than the single ropes of conventional drum hoists. Because of the better strength to weight ratios that can be achieved much deeper winds can be permitted before existing safety factors preclude greater depths. In South Africa there are presently two shafts that have been, or are being, sunk to the 10000 foot mark (the South Deep mine, at 8858 feet of a planned 9842 feet at the time of the visit, and Vaal Reef's Number 11, at 7677 feet of a planned 10334 feet. The Moab Knotsong mine (formerly Vaal Reef), when ultimately sunk to 4000 m, or 13123 feet, will be the deepest single lift shaft in the world.

Not to be forgotten in any description of the world's great shafts and mine hoisting plants is the Quincy Mining Company's Number 2 Mine hoist, completed in 1920 near Hancock, Michigan, in the United States of America. Still ranked as the largest mine hoist ever built, the design featured bi-cylindro conical drums some 30 feet in diameter at the largest end, with 10-foot long

cylindrical centre sections tapering down to 15-foot diameter 10-foot-long end sections. The length of wind on the two inclined skipways was almost 9300 feet (ASME Web-site).

In South Africa it was stated (Van Zyl, 2000 04 18) that all of the ropes used on drum winders are presently six-stranded of triangular construction. Non-spin ropes are currently used on the two Koepe hoists in the country, as guide ropes, and on kibble winders (in shaft sinking).

In the United Kingdom, the mining industry has been in great decline in the past two decades. Scores of pits have been closed after the end of generations of subsidies to support inefficient British Mines. The reasons for the loss of mining are legion but include the resistance of trade unions to the introduction of mechanization and the ability of consumers to purchase coal from Germany, South Africa, and Eastern Europe for a fraction of the cost of mining it in Great Britain.

At present, it was stated (Williams, 2000 05 24) that there are some 16 active shafts in the United Kingdom today. Several of these, the deepest being 1100 metres, are located in the deep Selby coalfield of Yorkshire. The only Blair (BMR) winder in the United Kingdom is installed at the Boulby potash mine.

In Germany, the mining industry is in a severe decline due to the ability of consumers to purchase coal at much lesser prices from elsewhere. The writer was advised that it costs about 300 Dm (about $220 Canadian per ton), while a ton of coal, transportation included, can be imported from the United States of America for about $50 US (about $75 Canadian). As the result, major coal-mining complexes are scheduled to close. Of the 12 in the country, one will close in 2001 and two in 2002. This will represent a 25% reduction in the coal mining industry in the next two years. It is anticipated that the industry will come to an end about 2010 - 2015.

It is to be noted that German mines are now complexes of former operators in an area. The typical complex may involve from 10 to 15 shafts and as many as 10,000 workers. Measured in human terms, employment in the industry has been reduced from 100,000 to 60,000 in the past decade, and will be reduced to 32,000 in the near future. Younger workers, from 25 to 35 years of age, are being advised to seek alternative employment.

Meanwhile, engineering enrolment in all disciplines in Germany has plummeted by 80% in the past five years. Employers are spending years to recruit new staff without success and talent is being imported from elsewhere. It was noted that the government is under pressure to reduce the time required for engineering studies from nine years to five years. There is a fear that a tremendous loss of expertise is taking place as older workers retire and are not replaced - there are simply no people to replace them!

At the mines, changes in personnel are taking place on a monthly basis as people are assigned to new duties. As has happened in Canada, it was reported that there are simply no personnel on the mine sites who "know the rope" (Spas, 2000 05 28). The turnover is so rapid that continuity has been lost.

In Poland (2000 06 01), it was noted that the entire European mining industry is in a state of severe decline. Mining has literally disappeared from France and Belgium.

As recently as five years ago, there were reported to have been 600 hoists in Poland. The number today has been reduced to 470, and will decline to between 380 and 400 by the year 2002. About 1980, 200 million tonnes of coal was produced annually. Annual production declined to about 120 million tonnes by 1989, and is presently 76 million tonnes. Employment has plummeted from 350,000 in 1980 to about 250,000 today, causing a major social problem of unemployment. It was noted that about 12% are presently jobless in the Kracow area and that the number has been predicted to rise to about 20%.

Throughout Europe coal mining is declining rapidly due to the ability of consumers to purchase less costly supplies from other countries. In Germany it was noted that coal was being imported from both South Africa and the United States of America. In Poland, South African coal is also being offloaded at Baltic ports for $19 US per ton, shipping included, as compared with the $40 US per ton that it costs to mine it in the country. A bright spot in the Polish mining industry, however, is in the growth of copper mining. It was mentioned that annual production has attained 400,000 tonnes of the metal.

In Poland, almost all of the shafts are less than 1000 metres deep. It was reported that the deepest had been 1212 metres, but that this had been closed a few years ago. The largest shaft in the country was reported to be 7.5 metres in diameter, with 30 tonne skips. The hoisting speeds were reported to be 20 m/sec. for materials, and 12 m/sec. for men (Hansel/Olesky, 2000 06 01).

Interestingly, it was mentioned that research has shown that a rope on a friction hoist can rotate on its axis up to 80 times during a wind.

During the author's conversations it was mentioned that, while there are a few drum hoists in Poland, the typical installation is a large tower-mounted friction hoist. Some of these involve as many as ten ropes on the drum with skips as large as 50 tonnes. It was noted that there had once been a technical barrier when slippage of the ropes on the drum at shaft depths greater than 850 metres. Some of the older friction hoists featured (and feature) large single ropes.

In Poland, detailed studies have been made of the types of hoists in use and the service that is demanded of these. It was mentioned that 72% of all friction hoists are single-rope, mostly old, installations. Of the remainder, 10% are double-rope hoists, and 18% are hoists on which four or more ropes are installed.

7. Ropes Commonly Used in Canada

At present, Wire Rope Industries, of Pointe-Claire, Québec, is the country's major manufacturer or wire ropes for mining. Once supplying about 80% of the ropes consumed by the Canadian mining industry, it is estimated that its share of the market has now declined to about 50% due to ropes entering the country from both South Africa and Europe. Wire ropes for mine hoisting, all of which are custom-manufactured to order, represents 35% of the firm's present business. Other firms selling wire ropes in Canada and their estimated share of the market are: Haggie Rand North America (30 - 35%); Northern Strands, Saskatoon Saskatchewan, representing Trefeuil Ropes, of France (5%).

In general, there are several principal uses of wire ropes in hoisting in mines. These are: (1) during shaft sinking operations; (2) as hoisting ropes on drum hoists; (3) as hoisting ropes on friction hoists; (4) as tail, or balance, ropes on friction hoists; and (5) as guide ropes for friction hoists.

During the conversations with rope manufacturers and users the Canadian pattern that emerged was:

(1) in shaft-sinking operations, 18X7 spin-resistant ropes are used at depths up to about 2000 feet; thereafter 34X7 spin-resistant ropes are used to depths of about 4000 feet; thereafter, the choices become: the "Fish-Back" pattern, manufactured in South Africa, Trefeuils's NOTORPLAST, manufactured in France, or locked coil ropes.

(2) for hoisting ropes on drum hoists, the commonly used ropes are flattened strand, flattened triangular strand, and six-strand rounded wires. Delorme (2000 03 22) noted that a few spin-resistant ropes had been imported from France and are is use at: Ruttan, in Manitoba; Barrick Gold's Holt-McDermott mine, at Hemlo, Ontario; and some of Falconbridge's operations, in the Sudbury area.

(3) as hoisting ropes on friction hoists the Canadian practice is to use flattened strand constructions for depths below 3000 feet and full locked coil ropes for greater depths. Examples of the former at the Sigma mine, at Val d'Or, Québec; and Mines Seleine, also in Québec.

(4) as tail, or balance, ropes beneath friction hoist drums the choice is between either non-plasticized or plasticized versions. Both 34X7 and 18X7 ropes are available in either type, and 34X19 plasticized rope was reported (Delorme) as being the most commonly-used rope for this purpose in Canada.

(5) for shaft guide ropes the current practice is to use either half-locked coil or non-rotating constructions such as 34X7.

In recent years plastic-cased ropes have been introduced to the mining industry. These are used only as balance ropes on friction hoists. An experiment in which coated ropes were tried some time ago on the drum hoist at the Panel uranium mine, at Elliot Lake, was reported to have been unsuccessful and has not been repeated (Delorme).

At the same time, it was noted that cross-cutting nicking of the strands of wires ropes, which had been a problem in the past, has been virtually eliminated through the introduction of coated cables.

Up to the present galvanized cables, while common and the standard in South Africa, have not been used in Canada to any great extent. That pattern is changing, however, as INCO's Ontario Division, in an effort to reduce the effects of corrosion, is in the process of replacing (as needed) all of its wire hoisting ropes with galvanized versions.

Further developments may bring the introduction of compacted-strand cables, which are reputedly superior because of their improved resistance to wear.

8. Ropes Commonly Used in Other Countries

During the visits, some interesting patterns of rope usage in other countries emerged. These were always due to either local preferences or local history.

For example, in the Republic of South Africa, it has been general practice to use six-stranded wire ropes on drum hoists for many years. As mines were developed at greater depths, however, it might have been expected that these would have been replaced with locked-coil or non-rotating ropes in order to avoid problems of torsional imbalance.

In fact, this never happened, the reason given being that there were too many difficulties in determining the internal conditions of such ropes with electromagnetic methods. This, together with the ease of inspection, the known behaviour of six-stranded ropes, and the known criteria for rope retirement has led to the continuing use of such ropes - even at great depths (Borello, 2000 04 17).

In the United Kingdom, however, the exact opposite is true. Virtually all of the wire ropes used in mine shafts today are of the locked-coil construction. These are used on drum hoists, friction hoists, and the country's sole Blair (BMR) winder.

The reasons for this are historical. With fleeting angles at the drum being limited to 3.5 degrees, it was found that if six-stranded ropes were used it would be required to design most drum hoist installations for multi-layer winding. With the higher-strength locked-coil constructions, however, it became possible to accommodate the entire length of the winding on a single layer while still remaining within the limits of acceptable fleeting angles. Thus, an entirely different pattern emerged!

In Poland, it was mentioned that triangular-stranded ropes are commonly used and that the largest rope in use in the country on a drum hoist is about 64 to 65 mm in diameter. It was also stated that the largest rope on a single-rope friction hoist was 80 mm in diameter, and was located in Germany.

As regards balance ropes, it should be noted that ropes of oval cross-section are used in South Africa while flat ropes, both woven and with cables embedded in rubber, are used in Poland. The latter often feature Warrington construction cables with special cores. It was mentioned that, while the lives of these balance ropes are exceptional, up to as much as ten years, there has been no effective means of assessing their in-situ conditions.

9. The Design of Hoisting Systems and Wire Ropes

A point that was made during the visit to Wire Rope Industries, in Pointe-Claire, Québec, was that wire rope is a consumable and is but one part of an entire hoisting system. Thus, while the focus of this study is on ropes, it must be acknowledged that ropes deteriorate not only because of normal wear and tear in service but also because of a variety of other conditions. Some of these result from the design of the hoisting plant and the installation of the wire rope, while others arise from the conditions encountered in the shaft. The conditions of the guides, the flow of ventilation (whether upcast or downcast), the presence of water, the acidity of that water, how skips are loaded, the dynamic as well as the static stresses applied to the rope, muck and other objects falling down the shaft and striking the rope, are all factors which will lead quickly to excessive rope wear.

While all of these can be controlled to a certain extent, either through improved design or operating practices, the point must be made that poor plant design, improper installation, poor operating practices, or a careless or neglectful mine operator can cause hoisting ropes to deteriorate very rapidly. Proper design and preventative maintenance are essential to the optimal functioning of a hoisting plant and to obtaining the best service from all of the components - including the rope.

The components of a mine hoisting system which must be subject to an engineering design are the shaft, the hoist, the headframe, the conveyances, and the rope. In the ideal world all should be selected concurrently so that a completely compatible design results. Where problems arise is when one component is designed in isolation from the others and retrofitting must be accomplished. Additionally, alterations to the shaft, particularly deepening to extend it, will have enormous implications on all of the other parts of the system.

In brief, in designing a shaft one has to be careful in choosing the best possible site and in identifying all of the uses, and particularly the capacities, that will be demanded of it. If deepening is likely at some stage, or if increased capacities are likely to be demanded in the future, it is highly desirable that these considerations be incorporated into the initial design.

Having considered the preliminary design of the shaft one can then address the selection of the hoist. In doing this, one must consider the entire system rather than simply the hoist alone. In general, the following are determining considerations:

(1) when hoisting is to be from several levels, double-drum hoists are indicated (the typical multi-level metal mine).

(2) when hoisting is to be from a single level, generally below about 1500 feet, friction hoists are the logical choice (the typical bedded deposit: salt, potash, etc.).

(3) for depths less than about 1500 feet, higher payloads can be obtained by using double-drum hoists.

(4) for depths of from about 1500 to 5000 feet, the higher payloads will be obtained from friction hoists.

(5) the limitation on the design of a hoist is the breaking strength of the rope(s).

(6) the size of the rope, in turn, will dictate the size of the drum to be used (in order to keep bending stresses to acceptable levels and, if a drum hoist, to provide adequate storage for the rope to be wound).

(7) in general, friction hoists are simpler and less costly to operate than drum hoists.

From this, it can be appreciated that the selection of a wire rope and the design of the drum on which it is to be wound are inextricably interrelated. Grave consequences will arise when these two components of the system are mismatched.

In the design of a hoisting system one must establish the duty cycle under which the hoist will operate, the distance between the loading pocket and the dump, the rate at which the production of ore is to be hoisted, the maximum load which can be handled in any trip, the weight of the payloads and the conveyance, and, finally, the diameter of the wire rope that will be required.

In summary, and according to Martin Dohm (2000 04 17), the factors that influence the operating capacity of a mine hoisting system are: (1) the factor of safety required; (2) the tensile strength of the rope; (3) the diameter of the rope; (4) the number of ropes to be used; (5) the factor of utilisation of the hoist; (6) the speed of hoisting; (7) the acceleration to hoisting speed; and (8) the skip factor, or size of the conveyance.

Likewise, all of the other parts of the hoist must be properly chosen. The bearings, the drive motor, the clutches, the brakes, and the control system are all integral to successful operation.

Of the factors which can cause the excessive and rapid wear of mine hoisting ropes, the following are perhaps the most important:

Concurrently, in the overall design, it is necessary to design the headframe to be used or the tower in which the hoist will be mounted. It is to be noted that there are mandatory requirements concerning: the ratios that must be obtained between the diameter of a hoisting drum and the rope wound upon it, and also between the hoisting drum and sheave wheels; the fleet angles at which the rope is wound on the drum; and the safety factors for the rope. An essential part of the maintenance of any hoisting system is to ensure that the profiles of the grooves are maintained on both the drum and the sheave wheels. The latter is very often neglected, and, during the visits, was mentioned frequently as being one of the leading sources of wear to wire ropes.

The design of a hoisting system is not simple. It requires considerable thought to ensure that all of the components are properly chosen and matched. This is no simple task, for, as Edwards (1992) has mentioned, there are no fewer than 277 sub-components, in

addition to the five major components that have been identified as part of the design of a mine hoisting system.

In the Republic of South Africa, Blair, or BMR winders, have been in use for several years. Especially suited for deep shafts, the Blair (BMR) hoists, feature two wire ropes which are wound simultaneously onto a split drum. With two ropes being attached to the skip it has been possible to achieve much greater depths of hoisting within the existing safety factors. The design takes advantage of the fact that two smaller ropes of the same total cross-sectional area as one larger rope will provide greater tensile strength. Double-drum Blair (BMR) hoists, then, feature no less than four ropes. It is to be noted that the two ropes used in a BMR hoist installation must be laid in the opposite directions in order to provide a torsional balance.

One of the problems that had to be overcome in the design of Blair (BMR) hoists was the maintenance of equal tensions in the two ropes which are attached to the skips. This is done through a compensating sheave which may be attached at either the skip or in the headframe (called "headgear" in South Africa). The former involves a drum which is attached above the connection of the ropes to the skip and requires that the two ropes be wound in opposite senses around it. Unequal tensions in the ropes will cause slippage around the drum until the tensions are equalized. The disadvantage of this is that severe wear takes place to the ropes at the points of slippage. Thus, frequent cut-offs become necessary.

The latter, with compensating sheaves at the top of the headframe, features sheave wheels which are free to float either upwards and downwards on hydraulic columns and with a connection between the two. Thus, the hydraulic connection permits an equalization of the loads on the two hoisting ropes. A decided advantage is that the large wheels at the top of the headframe cause much less wear to the wire ropes.

During the writer's visit to the Republic of South Africa four major installations of Blair (BMR) winders, encompassing all of the major variations, were viewed. The details are provided in Appendix III to this report.

During the author's visits, some observations were made concerning the grooving of hoisting drums, which is done to facilitate the winding of ropes in an orderly fashion. In particular, the Le Bus style of grooving was subjected to the criticism that, while it is particularly effective in facilitating winding, it has been found to result in excessive wear to the ropes. It was noted that severe wear results when the same points of contact are maintained between the ropes on successive winds, and at crossover points. Further, large gaps can be caused between the outer windings and the sleeve of the drum. When subsequent turns of rope in the layers above descend into these gaps the result can be exceptionally high contact stresses and crushing of the layers below.

Finally, it is a well-known fact that wire hoisting ropes begin to deteriorate the instant that these are placed in service. It is mentioned many times in this report that one of the criteria for the removal of wire ropes occurs when a 10% loss of breaking strength has been detected. One

option for the conservative designer, therefore, is to allow for an extra 10% in the metallic cross-sectional area of the rope so that any losses never will place the rope below the factors of safety intended in the design. This is a conservative approach which may have little impact in shallow and medium-deep mines. For deep mines, however, it can make a significant difference in the final depth of the shaft.

In the words of Martin Dohm, hoisting safety is more than defining design factors. It involves using both the "safe life concept" and the "fail safe concept". In the "safe life concept", one must consider the damage to a wire rope which takes place through fatigue. Key to this is the philosophy of the S/N curve through which one can relate the life of a rope in terms of the numbers of cycles through which it can be operated (N) with the loads that are placed upon it (S). During the operation of the rope the keys are to eliminate all of the initial defects, to prevent any damage from taking place, and to replace it promptly when the time arrives.

In the "fail safe concept", the keys are to design adequate redundancies into the system, to use excellent inspection systems, to develop means of arresting damage, and to limit the amount of in-service damage to he rope.

10. Safety Factors

In the design of mine hoisting systems it has been traditional for engineers to be conservative in the selection of safety factors. As is mentioned several times in this report the wire hoisting rope is the lifeline of the mine. If the rope fails it is likely that the consequences will be severe, if not catastrophic. Loss of life, damage to the shaft and its fittings, and suspension of production are the three most serious consequences.

The safety factors used in designs have been chosen on the basis of long experience. These are intended to guard against unexpected occurrences through which the hoisting rope could be overloaded and fail. These include: the loss of strength as the rope ages and wears; dynamic shocks caused by dumping loads in the skip; acceleration and deceleration; and emergency braking. There are three points in the rope where static stresses are of particular concern. These are: (1) at the hawse hole, where the rope is attached to the drum, and crushing forces are at the greatest; (2) at the head sheave, where the maximum load is suspended at any point on the rope; and (3) at the cappel, where the conveyance is attached, and where corrosion and bending stresses are probably the worst. The safety factors used for the design of drum hoists are calculated at two of these points: at the attachment of the rope to the conveyance/skip (cappel) and at the sheave.

For friction hoists, the safety factors are calculated at the drum and in the tail (balance) ropes. Additional factors apply to the guide ropes also used in hoisting.

(1) Canadian requirements.

In most Canadian jurisdictions it has been common practice to use the following as factors for drum hoists: (1) 5.0 at the sheave, calculated by dividing the strength of the rope by the maximum possible suspended weight; (2) 8.5 at the attachment of a rope to a cage, calculated by dividing the strength of the rope by the weight of the cage plus its maximum load; and (3) 7.5 at the attachment of a rope to a skip, calculated by dividing the strength of the rope by the weight of the skip plus its maximum load [R.R.O. 1990, Regulation 854, Section 228, (12) a - c] [Québec, S-2.1, r.19.1, art. 288].

For friction hoists an empirical relationship is used. Based on Swedish practice (Sweden being the country where this type of hoist was developed), this is:

$$SF = 9.5 - 0.00246L$$

where SF is the Safety Factor, and L is the maximum suspended length of the cable, in metres [Québec, S-2.1, r. 19-1, art. 289].

In Ontario, the regulation is expressed as follows [R.R.O. 1990, Regulation 854, Section 228, (13) a - b]: "The factor of safety of a hoisting rope installed on a friction hoist shall not be less than the greater of:

(a) the factor obtained from the formula

$$SF = 8.0 - 0.00164d$$

where d is the maximum length of the rope in metres, in the shaft compartment below the head sheave or the drum of a friction hoist; or

(b) 5.5

Additionally, factors of 7 and 5 are used for balance (or tail) ropes and guide (or rubbing) ropes, respectively {R.R.O. 1990, Regulation 854, Section 228, (14) and (15)] [Québec, S-2.1, r.19.1, arts. 291-292].

In Québec a significant change is about to take place through the introduction of modifications to the Regulation on the Health and Safety and Security of Workers in Mines. To be introduced on June 1, 2000, the first change concerns braking [Québec, S 2-1, r. 19.1, art. 225] while the second concerns the introduction of a newly-permitted safety factor and the conditions which accompany these [Québec, S-2.1, r.19.1, art.288.1]. In essence, the new regulation will permit the use of safety factors that have been established using the South African Bureau of Standards proposed "Code of Practice for the Performance, Operation, Testing and Maintenance of Drum Winders Relating to Rope Safety" as well as requiring, as conditions, that all aspects of both this code and the "Code of Practice for the Condition Assessment of Steel Wire Ropes on Mine Winders" (SABS 0293:1996) must be respected.

This is an extremely important step in the evolution of mine hoisting practices and will most certainly have far-reaching implications for the industry.

In essence, the South African Code permits the calculation of the safety factor according to the formula

$$SF = 25000 / (4000 + L)$$

where L is the maximum suspended length of the rope in metres.

It can be appreciated immediately that, for a shaft which is 2000 metres deep, the factor may be slightly above 4. For deeper shafts, an even lesser factor may be permitted.

In doing so, however, the mine operator must respect and follow all of the requirements which are included in the codes. These include not only many aspects concerning the design, performance, and operation of drum hoists, but also provisions regarding the monitoring and control of such systems, requirements for inspection, testing, and maintenance, braking, loading conveyance, and assessing the conditions of wire ropes. Simply stated the new South African code permits reduced safety factors provided that very rigorous care is taken to ensure that all parts of the systems are maintained in first-class condition, checked continuously, and operated in a way that dynamic stresses are reduced to the greatest extent possible.

This is no light matter, since, in South Africa a distinction is made between "Class I Winders" and "Class II Winders". The conditions accruing to both of these will be described in the following sections of the report, but, it has been said that if the Class II Winder can be likened to the pickup truck, which is the standard North American hoist, the Class I Winder is similar to the Formula 1 Racer! The requirements are very demanding.

And so these must be. If one is to permit reduction in safety factors the only way in which this can be justified is to reduce the conditions which caused these to be chosen at higher values in the first place. Rope deterioration and dynamic loading are two of the several causes that are addressed in the new code.

As a matter of background, the change was driven by Agnico Eagle's desire to deepen the shaft at its Laronde mine in order to permit the exploitation of ore reserves in the lower parts of the deposit. The writer was advised by the Commission de la Santé et de la Sécurité du Travail (CSST) (2000 03 30) that this had been studied in great depth by a committee of specialists and that the decision had been made to facilitate this through the adoption of the South African Codes of Practice as a part of the Québec regulations. It must be stressed that all parts of the South African Code, without exception or exemption, have been included. It was noted to this writer that if any part of the Code of Practice is found to be in conflict with the existing Québec Regulations, it is the Code of Practice that will prevail and take precedence.

(2) American requirements.

In the United States of America, distinctions are made based on the depth of the operation. For drum hoists for which the maximum suspended length of wire rope is 3000 feet or less, the safety factor is:

$$SF = 7 - 0.001L$$

where L is the maximum suspended length of the rope in feet.

The minimum value which can be calculated is 4, and this also applies for all depths greater than 3000 feet (57.19021(a)), (i.e. US MSHA Regulations, Part 57, Section 19021 (a)).

For friction hoists for which the maximum suspended length is 4000 feet or less, the factor is:

$$SF = 7 - 0.0005L$$

The minimum value which can be calculated is 5, and this applies to friction hoists operating for greater depths (57.19021(b)).

Factors of safety of 7 are also specified for tail (balance) ropes (57.19021(c)).

It is noteworthy that the factors used in the United States of America are generally less than those used in Canada. While it is true that there are few shafts deeper than 3000 feet in the USA, the factors are, nonetheless, used in a similar sense in the design of hoisting plants.

It has been mentioned that none of these apply to shafts which are used exclusively for the hoisting of rock and in which personnel do not travel (occasional inspections are excluded).

(3) South African Requirements.

In the Republic of South Africa it was mentioned during the author's meetings at the Council for Scientific and Industrial Research (CSIR) that both the winding practices and factors of safety were re-visited in discussions which began some 20 years ago. Proposed changes to the regulations were introduced, and were finally included in the Minerals Act and Regulations, as amendments in November, 1999. In it, reference has been made to the SABS Code 0293:1996, as amended, the South African Bureau of Standards', Code of Practice, Condition Assessment of Steel Wire Ropes on Mine Winders (references) (Minerals Act, Regulation 16.33). Reference has also been made to a second Code of Practice, on the Performance, Operation, Testing and Maintenance of Drum Winders Relating to Rope Safety. SABS Code 0294, as amended (Minerals Act, Regulation 16.34.2 (b)). It is to be noted that the latter is still in draft form.

The advantage of this arrangement, whereby SABS Codes of Practice, as amended, have been enacted into the Minerals Act, is that it is much more straightforward to make subsequent amendments to the SABS Code of Practices than it is to the Minerals Act. This is a model which could be used elsewhere, and which, in effect, will be used by the Province of Québec, as the result of its enactment of the SABS Codes in June of this year.

These have led to the introduction of two levels of safety factors. The first, which apply to Class II Winders are for those hoists which do not meet the new standards which are required for Class I Winders. Simply stated, Class II Winders (hoists) probably correspond to the average hoist which we know in Canada. While perfectly good installations, these do not compare with the more sophisticated systems which are now found in South Africa and which are designated as Class I Winders (hoists). These highly sophisticated hoists feature systems for: operation, monitoring (of both the hoist and the wire rope), inspection, braking, absorption of shock, and control of dynamic loading. At the time of the writer's visits, many of these features were beyond the requirements of the Minerals Act (references).

The Minerals Act presently specifies (regulation 16.34.1) that "Where a winding system operating in a vertical shaft and not using a balance rope is such that it allows for the periodic testing of the winding rope as required by regulation 16.41.1.1" (i.e., samples cut from the end attached to the conveyance...at intervals not exceeding six months), "the winding rope must have a breaking strength at installation of not less than - (a) eight times the attached load; and (b) four and a half times the suspended load.

For Class II Winders the safety factors at the attachment of the rope to a conveyance and the sheave are 8 and 4.5, respectively. Known in South Africa as "Capacity Factor" and "Static Factor", respectively, both are 0.5 less than those presently required in Canada.

For those winders equipped with a rope force compensator, such that the failure of one rope will not result in a momentary lowering of the force in the other rope (noting that 2-rope Blair (BMR) hoists are common), the Regulations (16.31) permit the Static Factor to be reduced to 4.275.

Going beyond this, if the winder conforms to the requirements of the SABS Code of Practice, the Regulations (16.29.2), further specify that the factor can be calculated according to the formula:

$$SF = 25000 / 4000 + L$$

where L is the maximum suspended length of the rope in metres.

In essence, the safety of wire ropes is being improved through Codes of Practice which will result in better control of the operational duty of mine hoisting plants. A key feature is that the loads on wire ropes will be monitored continuously.

In South Africa, it was mentioned that the factor of safety at the attachment of the rope to a conveyance for inclined shafts is 10. This is due to the exceptionally severe wear that takes place as ropes are dragged over guides and the debris that accumulates on the slope side of such shafts. Current practice also requires that the terminations of the ropes must be replaced every six months. It was once required that 3.7 m (12 ft) be removed every time that the termination is changed. This is now unspecified, however, as greater lengths may need to be replaced.

The actual regulation (16.34.3) reads "Where a winding plant operating in an incline shaft allows for the testing of the winding ropes as required by regulation 16.41.1.1, the winding rope must have a breaking strength not less than - (a) ten times the incline component of the attached load, and (b) five times the incline component of the suspended load". During the visits in the United Kingdom (Chaplin, 2000 05 25), it was observed that discard of the rope must take place when this is calculated as having been reduced to 9 - corresponding to a 10% loss of strength of the rope. In the Minerals Act (16.33) it is specified that the conditions of ropes must be assessed in accordance with the SABS Code of Practice 0293, and that these may no longer be used if the condition thus assessed at that point in the rope has reached the discard criteria.

It was also noted in the conversations (Zondi, 2000 04 18), that the factors of safety applicable to friction hoists are presently under review in South Africa. Increasingly, the country is moving heavily towards having Standards in place behind the Regulations. Close attention is being paid to the context in which safety factors and Codes are being used. Ultimately, shaft sinking will also be covered by the Regulations.

At present (Minerals Act, 16.35), "the breaking strength of the rope must not be less than 8.1 times the suspended load, provided that this factor may be reduced by 0,00135 for every metre of the effective length of the rope, but the safety factors must not be less than:

(a) 6,75 where the conveyance is suspended by a single winding rope; or
(b) 6,19 where the conveyance is suspended by 2 or 3 winding ropes; or
(c) 5,62 where the conveyance is suspended by 4 or more winding ropes"

In effect,

$$SF = 8.1 - 0.00135L$$

where L is the maximum suspended length of the rope in metres.

In addition, for Blair (BMR) hoists, regulation 16.37 specifies "Where a winding system operating in a vertical shaft and not using a balance rope allows for the periodic testing of the winding ropes as required by regulation 16.41.1.1 and each conveyance is suspended by two or more winding ropes in conjunction with a rope-tension compensating system which is constructed in such a way that the failure of one rope will not result in a momentary lowering of the force acting in any other rope, the breaking strength of the winding ropes at installation must be as specified in regulation 16.34.1 (a) or 0,95 times that specified in regulation 16.34.1 (b), whichever is the greater."

For balance ropes, these "must not be used in (sic) its breaking strength at installation is less than five times the combined weight of the balance rope and one half of any tail carriage and sheave" (Minerals Act, 16.39).

For guide ropes, the factor of safety must not be less than five, and is calculated by considering the combined weight of the rope and its tensioning weight (Minerals Act, 16.40.1).

Finally, for stage ropes, the factor of safety at installation is not less than 4,5, and is calculated by using the combined weight of the effective length of rope and its share of the attached load (Minerals Act, 16.41.1.2).

As in the United States of America, these factors do not apply to shafts which are used exclusively for the hoisting of rock. It was for this reason that the Elandsrand shaft was chosen for the field experiment in which reduced sizes of ropes and safety factors were, and are, being evaluated.

(4) Requirements in the United Kingdom.

In the United Kingdom, it was reported (Williams, 2000 05 24) that the regulations specify that the safety factor at the drum of a drum winder (roughly equivalent to the factor at the sheave) shall not be less than 6.5. This is much higher that the factors of 5 and 4 used by Canada and the United States of America, respectively.

During the conversations it was noted that the factors were originally specified during the age of steam hoisting plants, when practices were very rough and crude in comparison with modern practices, and that, because of the relatively shallow depths of British mines, there had been no pressures to change (reduce) these. In the days of steam winders, cages and skips usually landed roughly on timbers placed across the bottom of shafts. This rough handling resulted in severe dynamic stresses in the wire ropes as well as bending at the connections to the loads as the ropes went slack. The result was that relatively high factors of safety were necessary.

During the subsequent years, however, improved hoisting practices and the addition of electronic controls to modern hoists has resulted in improved wire rope safety through the higher factors which were embedded in practice. It was noted (HSL) that the last incident of a winding rope breaking in service in the United Kingdom occurred in 1965.

(5) Requirements in Germany.

In Germany, the regulations specify that the Safety Factors for hoist ropes shall be the following at the time of installation (TAS 6.9.1):

For man-hoisting operations (i.e. cages)

$$SF = 9.5 - 0.001L$$

and, for materials transportation

$$SF = 7.2 - 0.0005L$$

> Where L is the maximum suspended length of the rope in metres (i.e. between the sheave wheel and the conveyance attachment, at the lowest position in the shaft of the conveyance and/or counterweight.

As regards these factors, it is specified that these are to be calculated in terms of static loading. In the cases of man hoisting and stage ropes (TAS 6.2.10) the Factor of Safety is to be obtained by dividing the breaking strength, as determined experimentally, by the static load. For all other types (i.e., applications) of ropes the Factor of Safety is to be determined by dividing the calculated breaking strength of the rope by the static load.

The difference is subtle since calculated breaking strengths are calculated using the aggregate method, in which it is the strengths of individual wires which are used to estimate the strength of the finished rope. It is to be noted that the factors are more conservative when personnel are to be transported.

Further, it is noted that "static load" is understood to be:

1) In the case of hoisting materials: the greatest loading of the rope that occurs during its regular operational use, whenever the conveyance and the counterweight are at their most unfavourable positions in the shaft.

2) In the case of hoisting men: the greatest loading of the rope, whenever the conveyance and the counterweight are at their most unfavourable positions in the shaft.

3) For all other cases: the greatest loading on the rope.

In the case of shaft-sinking operations (TAS 6.9.2), the Factor of Safety is to be calculated from:

$$SF = 9.5 - 0.001L$$

For balance ropes, the Factor of Safety must be greater or equal to 6, and is calculated in respect of the weight of the rope (TAS 6.9.3).

When ropes are re-used the Factors of Safety must be determined in accordance with the requirements of TAS 6.9.1 and TAS 6.9.3, as listed above. The reduced breaking strength of

such ropes, however, as determined through the procedures as specified in TAS 6.3.2.15 must not be more that 10% of the respective breaking strength of new ropes (TAS 6.9.4) (i.e. losses of initial breaking strength greater than 10% will lead to rope replacement).

At the time of installation, the Factor of Safety of stage ropes must be equal or greater than 7.5, with respect to the greatest static loading (TAS 6.9.5). The same factor applies at the time of installation to the rope of grab-buckets, with the maximum load being the static load of a fully loaded bucket (TAS 6.9.6).

Next, guide and rubbing ropes, at installations with guide ropes, must have Factors of Safety greater than, or equal to 4.5. These factors are to be calculated by considering the combined weight of the rope and of its tensioning weight (TAS 6.9.7).

Finally, all other mine ropes must have Factors of Safety greater than, or equal to 7.5, with respect to their greatest static loading (TAS 6.9.8).

(6) Requirements in Poland.

In Poland, as mentioned, most of the hoists used are friction hoists. These range from single-rope installations to multi-rope hoists in which up to ten ropes are used.

For single-rope (note: "cable" in the regulations) hoists operating at depths up to 400 metres, the regulations (2.1.2.1.1, p. 166) specify that the factors of safety shall be 7.5 for the transportation of personnel and 6.5 for the transportation of minerals (note: "output" in the regulations).

For the same single-rope operations, when hoisting is from depths between 400 and 1200 metres, the factors of safety are:

$$n = 7.5 - 0.001\ (H - 400),\ \text{and,}$$

$$n = 6.5 - 0.001\ (H - 400)$$

for the transportation of humans and output, respectively. Where "n" is the factor of safety, and "H" is the length of the rope from the "cable wheels, drum or driving wheel to the skip in the lowest position", in metres.

For multi-rope installations, when hoisting is from a depth of up to 400 metres, the factors of safety for the transportation of personnel and minerals are 7.2 and 6.2, respectively (2.1.2.1.2, p. 166).

When hoisting is from depths between 400 and 1200 metres, the factors of safety are to be calculated as follows:

$$n = 7.2 - 0.001\ (H - 400),\ \text{and,}$$

$$n = 6.2 - 0.001\ (H - 400)$$

for the transportation of men and materials, respectively.

Finally, for depths in excess of 1200 metres "the required safety factor is constant and retains the value calculated for a depth equal to 1200 metres" (2.1.2.1.3, p. 166).

In the regulations the "Safety factor means the ratio of the actual breaking strength of the cable as a whole, designated by the manufacturer or determined in accordance with point 2.1.2.3., to the maximal static load" (2.1.2.2., p. 167). In point 2.1.2.3 (p. 167), it is specified that "The actual breaking strength of the cable should be accepted in accordance with the data designated by the manufacturer. In the case of a lack of such data, one should rely on the results of breakage tests of the cable as a whole or, in exceptional cases, calculate the breakage strength by accepting the following values of a nominal strength efficiency, i.e. the ratio of the actual breaking strength of the cable as a whole to the nominal breaking strength of the cable:

1) for cables of a closed or semi-closed construction and single-wound cables,

$$\eta_{on} = 0.9, \text{ and,}$$

2) for double-wound single layer cables,

$$\eta_{on} = 0.86, \text{ and,}$$

3) for double-wound multi-layered cables,

$$\eta_{on} = 0.79$$

where: η_{on} is the nonimal strength efficiency factor, calculated as described above.

For cables of a new construction, the manufacturer is obliged to designate the actual breaking strength" (2.1.2.3., p. 167).

It is further noted that "In hoists with a two-drum machine, the suspension cables should be employed in accordance with the standard introduced for obligatory application" (2.1.2.5., p. 167), and "In multi-cable hoisting installations, the number of cables should be even and there should be an equal number of left-handed and right-handed cables, made in the same production plant according to the same technology" (2.1.2.6, p. 167).

Further, very detailed, regulations specify the procedures and equations that are to be used in calculating the cross-sectional areas of ropes, and in verifying the factors of safety (2.1.2.8. - 2.1.2,11., pp. 167-168).

For balance ropes, the factor of safety should be 6 (2.1.3.1., p. 169), and for guide and fender (rubbing) ropes it is specified as 5 (2.1.4.2., p. 169).

The regulations further specify that only ovally-stranded non-unravelling ropes or other approved non-unravelling ropes should be used in single-rope applications (2.1.5.1., p. 169). Further formulae are given through which one may calculate the "relative unravelling coefficient" (2.1.5.2. - 2.1.5.3, p. 169). The implication of this is that, for locked-coil ropes,

payloads must be reduced rapidly when hoisting is from depths greater than 1,500 metres (Hansel/Olesky, 2000 06 01).

Finally, ropes for the suspension of "technological equipment" the required factor of safety is 7 (2.1.6.3, p. 170).

(7) Requirements in Australia.

In the province of New South Wales, in Australia, a number of Safety Factors have been specified. These have been established based on the use of the shaft, and, in the case of friction hoists, on the number of ropes employed.

For drum winders, it is specified (NSW Guidelines) that the factor of safety should be calculated by dividing the breaking force of the rope by the sum of the maximum load to be raised or lowered "plus the total mass of the rope acting as load due to gravity when fully let out". The breaking force of the rope to be used is to be the lesser of either the breaking force for the new rope or that determined in subsequent breaking tests. In other words, the safety factors will become less as the rope loses strength due to ageing and wear.

(1) For the transportation of personnel, or whereby the safety of personnel is involved, the factor of safety shall be calculated as follows:

$$S.F. = 7.5 - 0.001L$$

where L is the "vertical distance in metres between the level of the top of the highest winding sheave and the level at which the winding ropes meet the suspension gear of the cage at its lowest position in the shaft".

(2) For transporting rock or materials, whereby the safety of men is not involved:

$$S.F. = 5.5 - 0.0003L$$

(3) For transporting rock in a shaft used exclusively for that purpose:

$$S.F. = 4.5$$

(4) For transporting a machine or part of a machine at a speed of less than 2 metres per second:

$$S.F. = 5$$

For friction winders, the factors of safety are to be calculated in two parts:

First, the factor, F_1, is to be calculated for the worst condition of load.
Secondly, F_1 or F_2 is calculated for the rope configuration at the time of installation.

Where, F_1 is the factor of safety for newly-installed rope to be used for hoisting personnel and F_2 is the factor of safety for newly-installed rope to be used for the hoisting of mineral or material.

Thus:

$$F_1 = 1.0 + \{ 4.5(R + C) / R (1 + 0.0051L^{0.5}) - 13.5 \}$$

where: R is the ratio of the diameter of the winding sheave to the diameter of the winding rope.
C = 35 when there is no deflection sheave, or C = 43 when there is.
L is the vertical distance, as defined above.

Next:

$$F_2 = F_1 - 1.0$$

where, F_1 is the factor of safety if personnel are hoisted, and F_2 is the factor of safety if mineral or material are hoisted.

(1) for the transportation of personnel, then, or when the safety of persons is involved, the minimum factors of safety for friction hoists are to be: 7.5, when a single rope is used

6.9, when 2 or 3 ropes are used, and,
6.3, when 4 or more ropes are used.

(2) for the transportation of rock or materials, the equivalent factors for single ropes, 2 or 3 ropes, of 4 or more ropes, are 6.8, 6.2, and 5.6, respectively.

(3) likewise, when rock is to be transported in a shaft that is used exclusively for that purpose, the equivalent factors must be equal or greater than 6.3, 5.7, and 5.1, respectively.

(4) for the transportation of a machine or a part of a machine at a speed of less than 2 metres a second, the factor must never be less than 5, regardless of the number of ropes used.

For balance ropes, the safety factors required shall be equal or greater to 6, regardless of the number of ropes used.

(8) General Comment

While visiting the University of Reading, in the United Kingdom, an interesting comment was made to the effect that different means are used to calculate the Factors of Safety in the various mining jurisdictions (2000 05 25). In South Africa, for example, the calculation is based on the breaking strength of the rope. Thus, actual values for strength are used. It appears to this writer that similar practices are followed in both Canada and the United States of America.

In the United Kingdom, however, the manufacturer's catalogue value for the minimum breaking load is used. It was noted that this use of a nominal (versus an actual) value of strength would result in somewhat different values for safety factors.

Finally, in Germany, the strength used is that which is calculated from a calculation of the breaking strength of the rope using the aggregate method (i.e., the sum total of the strengths of the individual wires). The problem that can arise from this is that, after strain ageing, the strength of individual strands will increase, and thus, the strength of the rope will be calculated as having increased. In actual tensile testing of samples of the entire wire rope, however, strength losses will be noted. It was pointed out that this is the greatest single problem of using the aggregate method (Chaplin, 2000 05 25).

11. Wear and Deterioration of Wire Ropes

From the foregoing it can be appreciated that any variation from good and well-established design or operating practices will have major implications on the operation of a hoisting plant. As mentioned, however, a wire rope is a consumable and must be expected to wear as the result of service. From the point of view of all concerned the objective must be to obtain as much use as possible while, at the same time, maintaining safe operating conditions. The wire rope is the lifeline of the underground shaft mine. Without it, nothing moves in the principal entry. It is in no one's interests that wire ropes should be allowed to wear to the point that these become unsafe. The purpose of inspections is to assess to conditions of ropes under operating conditions and to make a judgement as to when these are becoming unfit for continued service and should be replaced. That judgement is both objective and subjective and will be addressed in the next section.

As a first step, however, it is meaningful to consider the causes of the wear to which wire ropes are subjected.

First of all, in addition to the tension caused by the weight of the rope, the conveyance and the payload below, bending stresses are induced in the rope whenever it passes over sheave wheels and is wound onto the hoist drum. It should be obvious that bending stresses in the rope will increase as the radius of curvature of the wheel over which it passes decreases. These stresses, if excessive, can result in a number of ways in which the rope can be damaged. One of the principal causes of damage is due to the internal wear which results from individual wires and strands moving with respect to each other. Others can include wires being elongated to the breaking point and wear on the external surface of the rope as it passes over the wheels. In one of its publications The United States Army estimates that the loss of strength due to bending around even a sheave or drum that is sufficiently large for its purpose can be from 5% to 6% (references).

Further, reverse bends should be avoided in order to prevent excessive internal shifting of the wires and strands. Thus, if the rope passes over a sheave in one direction it should be wound onto the drum in the same direction. The drum and the sheave should also be as far apart as possible in order to minimize the damage due to rapid repeated bending.

In South Africa, it is common practice to use two-rope Blair (BMR) hoists on deep shafts. This is for the reason that two hoisting ropes of smaller size but with the same total cross-sectional area than a single rope on a drum hoist will be stronger, and this will permit a deeper shaft within the same limitations of safety factors. In doing this, however, one of the technical challenges is to maintain equal tensions in both of the cables. As mentioned above, there are two ways in which this can be done. One is to pass both ropes attached to the conveyance around a compensating sheave (in opposite senses) which is affixed above it. The second, which causes less wear on the ropes, is to pass both of the hoisting cables over their respective sheaves, but to have each of these sheaves floating on hydraulic columns which are connected.

In the first option, the ropes slip at the points of contact with the compensating sheave. This, together with the bending stresses that result from winding the rope around the sheave (the

D:d ratio is probably of the order of 50:1), is probably responsible for the fatigue, excessive wear, and very rapid deterioration which has been found to result. The South Africans were quick to point this out (discussions at Miningtek) and to urge that any potential users of Blair (BMR) hoists in Canada should be made aware of this problem. This was not intended to deter the use of such hoists, but, rather, to make Canadian operators aware of the fact that it would probably be necessary to cut off about 20 m of the front end of each of the two cables (at the attachment to conveyance) every few weeks. It was noted that this can be done as frequently as every seven to eight weeks in South Africa.

At present, in order to ensure that bending stresses are controlled, the mining regulations specify the ratios that are required between the diameter of a hoisting drum and the rope which is to be wound upon it. Traditionally, this has been 80:1. Good practice, however, indicates that the bending stresses induced in the rope by winding can be reduced considerably by increasing the ratio, and, consequently, the size of drum hoists. In existing operations, in which shaft deepening is proposed, this may not be readily accomplished. Nonetheless, in a new operation, when the entire design of the hoisting plant can be established at the beginning, it is perhaps viable to suggest that the largest possible winding drums could be installed. The writer understands that this thinking has influenced the design of the hoist at Agnico Eagle's new Laronde mine Number 3 Shaft, in northwestern Québec, where a drum:rope ratio of 100:1 has been selected.

Second, wear of the wire rope is also influenced by the speed at which it is wound around sheaves and drums. The problem was noted as being particularly acute for rapid frequency skip hoisting, where wear is the main factor in rope replacement (OMOL). Another recommendation is that the speed of winding should be as low as possible for the work required. There should also be a monitoring and recording of the numbers of cycles that are being imposed on ropes.

Third, excessive wear results from improper installations of the components of a hoisting plant which result in misalignments of sheave wheels and drums. As a consequence, rubbing can be added to bending.

Fourth, ideally, wire rope should be wound on a drum in smooth layers without overlapping the turns. While a certain amount of crushing will result from rope under load being wound, either onto the drum or onto previous layers, overlapping can cause a plucking of the external wires as the rope is unwound. To address this, the mining regulations include provisions for the grooving on drums, the number of layers which can be wound, and the "fleet angles" that are required as the rope is wound.

Fifth, the construction of wire ropes results in the wires and strands being wound around each other under tension. Because the stress concentrations are very high (theoretically infinite !) When two circular surfaces are in contact, the result can be either or both of plastic deformation and cross-cutting nicking of the wires. This can result in reduction of cross-sectional area or breaking of the wires. Delorme (2000 03 22) noted that the introduction of plastic-impregnated and coated (balance) ropes had virtually eliminated this problem. For the same reason it is essential that the profiles of the grooves on drums and sheave wheels must be matched to the diameter of the rope being used. Incorrect grooving will result in high contact stresses and exceptionally high wear.

Sixth, excessive dynamic stresses can result in severe damage, and possibly failure, of a wire rope. The factors of safety at the attachment of the rope to the conveyance and the sheave which the regulations prescribe are based on the relationship between the ultimate breaking strength of the rope and the static load which is suspended from it at the point at which the safety factor applies (i.e., the weight of the rope below, the conveyance, and the payload). Thus, the factor of safety of 5 at the sheave means that the total suspended load on the rope at the sheave must not be more than one-fifth of the ultimate tensile strength of the rope. In other words, at maximum load at the sheave, 80% of the strength of the rope must be available as "reserve strength".

Those actions which can result in dynamic stresses, however, can place severe demands upon the strength of a wire rope. In mine hoisting, the most important of these are the stresses resulting when loads are suddenly dumped into the conveyance at the loading pocket and braking. Delorme, in a presentation (2000 03 22) to the Ottawa Branch of the Canadian Institute of Mining, Metallurgy and Petroleum entitled "Evolution of Hoisting with Wire Rope - Yesterday, Today, and Tomorrow" estimated that the peak loads caused by dynamic stresses could be as much as 40% of the breaking strength of a wire rope. To address this problem, in South Africa it is now required that skips in deep shafts must be chaired while being loaded. One could probably suggest that this, and similar provisions for both braking and emergency braking should be included in a Code of Practice for hoisting. Included in any provisions for emergency braking should be the requirement that the attachment of a rope to a cage, or the cage itself, must be able to resist the effects of dynamic forces. It is to be noted that a major accident in South Africa resulted when a cage loaded with miners became stuck in the guide ropes. Not being aware of this, the hoistman continued to lower rope into the shaft. Meanwhile, the miners began to jump in the cage. As the result of this, the cage broke free and plunged downwards, with the attachment of the rope to the cage breaking due to dynamic stresses once the slack in the rope had been eliminated and the full load of the falling cage was applied to the rope. All onboard the cage were killed.

Seventh, one fact which has emerged during this study is that the behaviour or wire ropes which are less than 1800 metres long (5905 feet) seems to be entirely predictable, while the behaviours of longer ropes are problematic (Goosen, 2000 03 14). Something, as yet unexplained, seems to happen which causes a waviness near the front end of the rope, or "proud strands" (bulging slack strands), or corkscrew deformation of the rope, or broken strands. It is suspected that the reason is that there may be slippage between the core and the outer strands in long ropes which results in uneven stress distributions and problems. Mine operators and regulators must be made aware of this problem that is particular to long ropes.

In conversations with Dohm and Borello (2000 04 17), however, it was noted that torque is produced when a helically-stranded wire rope is loaded and that the torque is proportional to the load applied. In drum hoist installations, however, both the front end (at the attachment to the cage or skip) and the back end (at the attachment to the drum) are fixed. Thus, the rope can not rotate, and the circumstances are such that the torque becomes very much greater. Since the torque can not be relieved, then, the result is that the lay length increases where the load is the greatest - at the drum -, and decreases where it is the least - at the conveyance. In a sense, the lengthening and contracting of the rope as it is wound and unwound is very much like a pump, with the result being that water and grit are admitted as it flexes and opens. The only solution is

to apply lubricant in copious quantities. Dohm (2000 04 17) stated that the opening of the lay length as the rope is wound out causes a distortion in the structure of the rope by crushing as successive turns are wound upon it. This can give the rope an oval shape, which, in its own right as a criterion, can provide sufficient ground for rejecting the rope.

In both shaft sinking operations and during those times when samples are obtained for destructive testing, however, the problem becomes very much worse. At this time the lower part of the rope is completely free of tension and becomes free to rotate and to unwind. Once the conveyance is reattached and the rope wound back and forth the net result is various changes in lay length along the entire length of the rope as it re-equilibrates to the fact that some unwinding has taken place at the bottom. In time, as further samples are obtained, the damage due to repetitive unwinding of the bottom of the rope becomes progressively worse. Professor Chaplin (2000 05 25) estimated that the increases in lay length at the back end could be as much as from 35% to 60%, while, at the front end, the decreases could be from 5% to 20%. It is to be remembered that the torsion over the entire length of the rope will be balanced.

For this reason, non-spin ropes must be used in sinking operations, but, even so, the difference in torque in the rope is accentuated at this time. Ultimately, this can cause waviness in the rope.

Notwithstanding this, a key point that emerged in the discussions (Chaplin, 2000 05 25) is that the root cause of the progressive damage due to unwinding lies in the poor maintenance practice of allowing the free end to rotate at the time that end cuts are made. The solution to this lies in clamping the rope to prevent unwinding at this time! How often has one heard that a new rope is "lively" during installation as it tends to unwind the torsion which has been locked into it during the winding of the rope and then winding it onto the reel? Again, rope should never be free to rotate axially during installation. It must be wound onto the drum under tension and never be permitted to rotate during the entire process. It was also noted that torque-balanced ropes are very sensitive to twisting.

Eighth, another cause of severe wear takes place during the winding and unwinding of the rope from the drum. When winding, it is to be recalled that the load on the rope is at its maximum. Thus, the rope is in a stretched condition when it is coiled upon the drum. During unwinding, however, since the load is much less, the rope tends to relax as it is played out from the drum. The result of this is that there is slippage between the winds of the different layers. This can result in excessive wear to the rope.

During several of the visits it was noted that the installation of wire ropes is a critical step as regards future performance. These must always be installed under tension on drums which have been properly maintained. In particular, the profiles of the grooves on both the drum and sheave wheels must match the profile of the rope being used. If not, and particularly at Le Bus crossovers on multi-layer windings on drums, the contact stresses will be very high and will result in the crushing of the rope. Further, the ratios between the diameters of the rope and the drum and the rope and the sheaves are important. If these are too low, severe bending stresses will result and the rope will be damaged very quickly.

Finally, and ninth, the forces and stresses to which the rope is subjected while it is being used will have a dominant influence on its life and performance. Excessive acceleration and deceleration, poor loading practices in which heavy loads are suddenly dumped into the skips, and emergency braking situations will all generate dynamic stresses which can severely damage a wire rope. This is one of the factors which can be largely controlled and is dealt with extensively in the SABS draft Code of Practice 0294.

The second major cause of damage to wire hoisting ropes has to be the corrosion which is caused by acid mine waters. This is particularly relevant to Canada since all of our base metals deposits are comprised of sulphide minerals and since other sulphides, particularly pyrite are found associated with gold deposits. Further, because of our climate and the abundance of water, Canadian mining generally takes place under "wet" conditions. Sulphide minerals, in the presence of water, oxidize to form sulphurous and sulphuric acid. Mine waters are generally very acidic.

Corrosion, due to acidic mine water coming in contact with a wire rope, is one of the most important causes of loss of metallic area and, consequently, strength. With careful examinations surface corrosion, normally seen as surface pitting, can be readily detected and assessed. Internal corrosion, however, is extremely difficult to detect and is perhaps only indicated as the result of destructive tests or in taking samples of wire rope apart in order to visually assess the internal condition. It can take place extremely quickly and have sudden and unexpected consequences - as in the recent failure of a wire hoisting rope that had only been in service for about six months at a mine in northwestern Québec.

Water is present in even a "dry" mine. One case that was mentioned concerned the unexpected corrosion of a rope at a point a few hundred metres below the sheave. Subsequent analysis revealed that the return ventilating air entered the shaft at this level and that the air was moisture-laden. The cause of the corrosion was found.

In seeking preventative maintenance against corrosion there are several options open to a mine operator. First, one can install wire rope in which the strands have been galvanized with a zinc coating. Such ropes are more expensive but perhaps also more sensitive to interstrand notching. Secondly, the use of lubricants is indicated. It is to be noted, however, that there are many possibilities and that the choice is not simple. Third, the use of protective coatings over the rope, such as plastic, may be required. The disadvantage of this option is that, apart from the condition of the plastic casing, it becomes very difficult to visually assess the in-situ condition of the rope.

During the discussions, one of the most critical problems that was identified was the excessive wear and tear that is caused to the lowest part of the rope during shaft-sinking operations. This is so great that the common practice is to cut off and discard the lowermost 50 to 100 feet periodically. It was noted that it is very difficult to track where these ropes are in the industry and the individual past histories. In theory, a wire rope must be re-tested every time that it is placed into service. Whether or not this is being done in all cases is very difficult to determine.

Heat is also a cause of the deterioration of wire rope. This can be either generalized heating, or localised heating, or, as mentioned in the New South Wales "Guidelines for Safe Mining" (references), due to lightning strikes.

From a metallurgical perspective, when steel is heated above 700°C and is then cooled suddenly, the result is that the internal structure is changed and it becomes both hard and brittle. In mine hoisting, this can occur when the wires of the outer surface rub on another surface. The damage may be only to the surfaces of the external wires and may be very thin. Nonetheless, this can result in broken crown wires.

Objects falling and striking the rope can result in severe damage, including severed wires and strands of the hoisting rope.

12. Assessing the In-situ Conditions of Wire Ropes - the Players and the Practices in Key Jurisdictions

Engineering practice has always involved the application of scientific and engineering principles to the design of engineered structures. The practice is evolutionary and continues to improve as better materials become available and as we become more aware of the reactions of these to applied loads and stresses, to the effects of time, and to environmental conditions. Unfortunately, there are occasional failures. The sad result is that these often result in loss of life. From these, however, if we are able to determine the causes, the result is usually an improvement in either design, or practice, or both.

The practices and procedures which follow vary from jurisdiction to jurisdiction. Some countries require destructive tests in order to "track" the loss of breaking strength in mine wire ropes while others do not. There are also differences between the safety factors that are specified (as elaborated above) and in the means of calculating these. There is one point on which there is no difference, however, and that concerns the necessity of making daily inspections and assessments of the condition of wire ropes. Whether this is covered either in the regulations or in the supporting practices which are recognized as underlying those regulations is immaterial. The essential point is that the wire ropes used for hoisting personnel must be inspected daily.

Thereafter, however, there are wide differences between the practices and the level of effort that accompanies these. The key point, however, is that the rope must be run at such a speed and under such conditions of lighting and comfort that it can be inspected in such a way that it is reasonably certain that visible damage can be detected. These would include broken wires or strands, bulging or "birdcaging" of the rope, waviness, or nicks and marks from objects that have struck it.

In Canada (Rotesco, 2000 09 07), it was noted that the cooperation received from the mining industry, in facilitating inspections, was generally very good. The conditions which surround such inspections, however, vary widely. In some instances inspectors are obliged to work outside, in severe ambient conditions. Lighting conditions range from excellent to terrible, while improvements need to be made in respect of the staging (or, rather, lack of it) which is provided when inspections are to be made at the drum. It was noted that there is "room for great improvements to provide improved facilities for inspecting ropes". In general, speeds of about 400 feet per minute are used during non-destructive tests.

In the United Kingdom it is considered that a speed of 5 feet per second is satisfactory. To the operators of deep shafts who may protest that such a speed would require twenty minutes for the inspection of a 6000-foot rope, it must be emphasized that the visual inspection is the primary line of defence and can not be omitted, not ever. It was noted in the discussions in Great Britain that such daily inspections have, historically, been the means of discovering problems with ropes - the main problem having been the development of waves.

Further, also in the United Kingdom, more elaborate visual inspections are required every 30 days. At this time a section of the rope must be cleaned every 100 feet for a thorough visual examination, measurements of diameter taken, and an inspection made to determine if there has

been corrosion. Following the inspection a prescribed report must be completed and this must be signed by both the Mine Engineer and the Manager.

In Germany, each test analysis is documented in a full report which is submitted in a report to the operating mine. It is to be noted that it is the mines which are the clients of DMT (Deutsche Montan Technologie) and not the inspectorates. Nonetheless, the operator is required to sign the copy of the report, insert it in the "Shaft Book", and send a copy to the inspectorate.

As regards ropes, the first report, the initial report, must be completed during the six weeks before the rope is installed. In effect, this is to determine if any strain aging has taken place and to establish the initial value to which all further determinations will be referred.

The "Shaft Book" is a document which contains a complete record of everything that has been documented in connection with the operation of the shaft. This includes all inspections of the shaft and its components.

In the report are given the properties that have been obtained from the aggregate test to calculate the breaking strength, the amount of work which has been done by the rope, the observations, and any recommendations concerning when the next inspection should be or when the rope should be discarded. Having signed the report, the Head of the Division at the mines is obligated to answer as to whether or not the recommendations have been followed.

Canada

In Canada, the pivotal event in the technology of mine hoisting with wire ropes was probably the disaster at the Paymaster gold mine, in Ontario, in 1945, when a badly-corroded rope broke and the cage, containing 16 miners, plunged to the bottom of the shaft.

From this flowed new mining legislation and the establishment of the Province of Ontario's Wire Rope Testing Laboratory in the basement of the Whitney Block, at Queen's Park, in Toronto. The present laboratory in the basement of the Willet Green Miller building, in Sudbury, is the descendant of that original facility. The laboratory was relocated in the early 1990s as the provincial government became decentralized and as pressures mounted to move the noisy facility from the premises of the Ontario Legislature. At one time, some destructive testing was done in the laboratories of the University of Toronto. This has not been the case for several years. At present, one of the few other facilities in Canada at which samples of wire ropes can be pulled to failure is in the Quality Control Laboratories of Wire Rope Industries, at Pointe-Claire, Québec. In the discussions at the plant, on 2000 03 21, it was mentioned that the company does not perform commercial tests as this may be viewed as a conflict of interest. It was also understood (Geller, personal communication) that DEVCO, in Nova Scotia, once tested its own cables.

Non-destructive evaluations of wire ropes are presently performed by a number of firms, which include: Centre Technologie, Noranda, Pointe Claire, Québec; Labcan, in Cap-de-la-Madeleine and Val d'Or, Québec; Rotesco, in Scarborough, Ontario; and Heath and Sherwood (Magnograph), in Kirkland Lake, Ontario. Apart from short periods of instruction which are offered by equipment manufacturers there is no formal program of study, or certification,

in Canada. It was noted (as it was in other countries) that there is nothing to prevent a person from purchasing an instrument and using it immediately.

Elsewhere in this report will be found the criteria which have been established for the removal of wire hoisting ropes from service. These have been established through long practice and experience. Experience indicates that wire ropes, if not exposed to damaging conditions, and if well maintained and used, can last for very long periods - up to 20 years in some cases. If, on the other hand, the use is severe and the environmental conditions are damaging, the life of a rope can be exceptionally short - as little as a few weeks or months.

Once again, experience also indicates that, once wire ropes begin to deteriorate, that deterioration is usually rapid. Thus, a key aspect in establishing the criteria has been the determination of that point beyond which a rope should not be used.

In active service a wire rope may begin to lose strength from the instant that it is installed. As the result of being flexed over the hoisting drum and sheave wheels as it is wound up and down the shaft the rope becomes work-hardened and loses some of its flexibility. Additionally, individual wires in the strands may be abraded, extended, or pinched by other wires to the point where these fail. While individual failures that are well separated from others are not dangerous in themselves, the cumulative effect of many such breaks is that the rope loses some of its initial breaking strength.

Initially, this loss may be very gradual. As time continues, however, the losses become progressively more rapid. Experience also indicates that in the range of 7% to 12% loss of breaking strength the deterioration is relatively slow. Beyond 12%, however, it is very rapid and carries with it the likelihood that the rope will soon break.

Thus, a 10% loss of breaking strength is universally considered to be a "comfortable point" at which a rope should be replaced (discussions at CSIR). This loss of strength is a "hard" criterion and can be measured *directly* through a destructive pull test. All of the other criteria are also directed towards causing a rope to be discarded when the loss in strength has attained 10%. None of these can be determined directly, however, and are, therefore, *indirect* tests. This is a key point, which is not to be forgotten.

One point of contention to which frequent reference was made, during the writer's visits, was that there is a lack of clear understanding as to how Loss of Metallic Area (LMA), as detected through electromagnetic methods, can be correlated with Loss of Breaking Strength (LBS), which can be measured through destructive pull tests. While it is a certainty that a Loss of Metallic area will relate to a Loss of Breaking Strength, it appears that absolute correlations are lacking. Further, it seems reasonable to the writer that both the constructions of the rope and the types of degradation (such as corrosion, broken wires, or wear) may have different effects. There needs to be research on this point.

In a following section the criteria for rope replacement will be listed and discussed individually in some detail. In summary, though, Canadian practice is generally that a rope must be evaluated

through both destructive and non-destructive testing at installation and at intervals of not more than six months thereafter. In addition, daily inspections, to detect defects, are also required.

United States of America

In the United States of America mining health and safety research originated and was driven by accidents in the industry, In the discussions at NIOSH and MSHA (2000 04 03-04) it was understood that about 3,000 miners were being killed annually during the early years of the 20th Century. That number has subsequently declined and stabilized at about 80.

For many years, the United States Bureau of Mines built and maintained one of the world's best wire rope test facilities at its Pittsburgh Research Center, at Bruceton, Pennsylvania. In the mid-1990s, however, the USBM was disbanded and much of their equipment, including their large fatigue testing machine, was sold to the Paulsen Wire Rope Corporation, in Sunbury, Pennsylvania (McKewan, 2000 04 04). There is no requirement for destructive testing in the United States of America, and the writer is not presently aware of other facilities which could perform tensile pull tests on samples of wire hoisting rope.

Subsequently, it was mentioned that the Paulsen company was purchased by the Kesar Rope Manufacturing Company, of Germany. The Kesar Company was reported to be owned by the Verreet family - and to be managed by a Mrs. Verreet and her four sons. As the story was told (Chaplin, 2000 05 25), the firm has been manufacturing three-layered, torsionally-balanced, non-rotating ropes for high-lift cranes for many years. The firm has expanded to producing wire ropes for mining and is presently supplying these to Australia. The Paulsen Company was reportedly purchased as a foothold into the American and Canadian markets (it is to be noted that the writer met Roland Verreet, of Aachen, while visiting in South Africa).

In a more recent development, it was reported to the writer that the ex-USBM machine is presently for sale and that an interest has been generated on the part of Wire Rope Industries, of Pointe Claire (personal communication from WRI in mid-May).

Non-destructive testing is mostly performed by NDT Technologies, of Windsor, Connecticut. Once again, there is no formal program of study or process of certification in place in the country.

Republic of South Africa

In South Africa the pivotal event that drove the inspection of wire ropes was the disaster at the Robinson Deep gold mine, near Johannesburg, in 1904 , in which 50 were killed when the rope broke and the conveyance plunged to the shaft bottom. South African mines are enormous by Canadian standards since reef mining is the norm and such operations are labour-intensive and spread out over vast distances. At present over 400,000 persons are hoisted daily in South African mines. At any moment of the day, around-the-clock, some 3,500 persons are in transit in South African shafts. The scale of operations is such that conveyances are large, sometimes comprising three or even four decks. The result is that, when shaft accidents do occur, many lives are lost.

At Miningtek (2000 04 11), it was mentioned that the CSIR's (Council for Scientific and Industrial Research's) rope testing facility was established in 1904 and that hundreds of thousands of rope samples have been tested since. At present the volume is about 3500 tests per annum - a decrease from former annual volumes of about 7000 tests. About two years ago, Haggie Rand, the South African wire rope manufacturer, and a subsidiary of the Anglo American Corporation of South Africa Limited, decided to make its testing facilities available to the mines of Anglogold and others. It was said (2000 04 13) that the market in South Africa is now evenly divided between the two players and that it seems to have stabilized.

It was noted, however, that Haggie Rand is only able to test ropes up to a diameter of 50 mm. All others of greater size, therefore, must be tested at Miningtek. During the conversations with Miningtek it was stated that Haggie's testing is a part of their service to their customers whilst at Miningtek it <u>was</u> their service.

As regards fees, Miningtek stated that it charges 1250 Rand to perform destructive tests on ropes between 30 and 50 mm diameter. For larger ropes, up to 65 mm diameter, the fee becomes 1750 Rand. For still larger ropes, such as for draglines, the fee is negotiated (O'Brien, 2000 04 13). As a framework of reference, the first-mentioned fees correspond to about $300 and $450 Canadian, respectively. It was added that the present fee structure is under review and will probably be revised upwards.

In South Africa, it was noted that there is a national database for all of the rope tests that have been performed. This is maintained by the DME/GME (District Mining Engineer/Government Mining Engineer). All players are required to submit their data for entry into it. It was said to be the only official database in the country, with all mines using it (Mostert, 2000 04 13).

Most non-destructive testing of wire ropes is performed by AATS, another Anglo American subsidiary. At present the firm inspects about 60% of the wire hoisting ropes in South Africa. The remainder of the NDT market is shared by two small independents. These are: a small unnamed firm which largely services the mines of the Goldfields Group, and; Cegelek Limited. Most inspectors were said to have been trained to one of the levels prescribed by the SABS Code 0293:1996. Those presently not certified have until September, 2000, to do so or to quit the market.

It is to be noted that AATS's wire rope inspection facility has received ISO 9002 certification. It is audited annually by ISO, semi-annually by AATS, and more frequently in internal audits. At Fochville it maintains the records of all of the rope tests that it has performed in the area since 1956. While it is acknowledged that much of these data are obsolete and of historical interest only, there is a reluctance to destroy the old data records.

In South Africa, destructive tests on "front end samples" (i.e. cut-offs at the conveyance) are required every six months, while tests at the "back end" (the drum) are required every three months. It was observed that only about 5 ropes are condemned each year and that this reflects the implementation of the Code of Practice as a standard and an improvement in the safety of wire ropes in the country. It was also noted that wire ropes are lasting longer and that this has brought important payoffs to the industry. It was also stated (discussions at Miningtek) that the major mining houses have exerted internal self-control. For Blair (BMR) hoists, however, as the result of a recent failure of a rope, tests at both the front and back ends are now required every three months (Zondi, 2000 04 18). To date, there has been no national database on wire rope failures. It was noted, though, that about 50 ropes have failed since 1988 and that most of these were in sub-vertical (inclined) shafts.

In South Africa (Dohm & Borello, 2000 04 17) there were very strong views that statutory destructive tests are not only meaningful, but also irreplaceable and indispensable. It was stated that not only are these the only absolute values of condition that are available but also that it is an excellent way of forcing operators to be mindful of "Rope maintenance at the terminations". Without the requirement there was concern that people could lose track of the conditions developing at the most critical points in a wire rope - with potentially disastrous consequences.

Prior to the recent introduction of SABS 0293:1996 the criteria for rope replacement were reported to have been based entirely on loss of breaking strength. While the most recent Code includes other criteria, it was emphasized that there is presently no acceptable substitute for destructive testing.

Finally, it was noted that South African Regulations require that a wire rope must be tested using a reliable instrument approved by the District Mining Engineer.

After the final approval of SABS 0294, probably in September, 2000, it was noted that the intention of the South African Bureau of Standards is to work towards an Internal Standards Organization (ISO) Standard. It was understood, through the discussions at the South African Bureau of Standards (2000 04 18), that this would be done through ISO Committee TC 82's Subcommittee 3, on "Mining Ropes".

A final point that was made in South Africa is that Factors of Safety of 3.0 are permitted for the stage winders used in shaft sinking inasmuch as the dynamic stresses on such ropes have been found to be exceptionally small (Van Zyl, 2000 04 18). It was noted, however, that, while stage winders which involve the winding of the ropes around two drums are acceptable, it was stated that Chimes Wheel Winders, in which a single drum is used, are potentially very dangerous and should be prohibited.

United Kingdom

In the United Kingdom an electromagnetic non-destructive testing device was developed by the National Coal Board. After the dissolution of the NCB, the device and the intellectual property were sold to a private firm, Ropescan. It is understood that no further development has been done on the instrument and that there is a concern that, if the firm vacates the field, there may be no other alternate suppliers in the country (HSL, 2000 05 24). Another firm, Servicore, was reported to have been well-trained and experienced in other areas of wire rope inspections and could certainly pick-up major problems in stranded ropes. In the words of HSL, wire rope testing in the United Kingdom "is a cottage industry in competition".

Germany

During the visit (DMT, 2000 05 29), it was mentioned that the German republic is a federation comprised of several Länder. Each of these have their own mining regulations (similar to the arrangement in Canadian provinces), but the main regulations are in Nordrhein-Westfalen, the centre of coal mining in the republic.

The organization presently known as the DMT (Deutsche Montan Technologie) has its roots in the WBK Rope Test Institute, which was formed in 1888 (Gronau, 2000 05 29). The rope testing facility was later known as the Seilprüfstelle (Beck, 1989), and later came under the DMT. The latter name, translated by the writer as German Mountain Technology, reflects the fact that the focus of wire rope testing in Germany is shifting from mining to other areas in which wire ropes are used - namely: in alpine ski lifts, cranes, elevators, and as anchoring cables for offshore platforms. At present, the mining applications are handled at Bochum while crane and lift cables are handled by the University of Stuttgart.

Also at present, the DMT is actively searching to expand its client base. It was noted that it has made the transition from a state-supported institution to one which must generate complete cost-recovery in order to survive. It was noted that the fees-for-service that are charged are sufficiently high to motivate potential customers to look elsewhere for potential suppliers (150 Dm, or about $110 Canadian for a technologist). During the visit, the laboratories were quiet, and this was evidently a concern. It was said that active efforts are being made to seek clients in other areas which the institute could possibly serve.

Poland

During the visit (2000 06 01), it was noted that the Department of Mechanical Engineering (GEM) of the Polish Government is the originator of all regulations in connection with the use of wire ropes. The country is divided into 13 Districts, with there being district inspectorates for each (the examples mentioned were Katowice and Silesia). It was noted that the inspectorates are concerned with all aspects of all products that are dug from the ground.

It was reported that there had been no problems with hoisting ropes in the last 20 to 30 years, but that there were, and are, severe problems with balance ropes due to both corrosion and spinning.

It was stated that there were approximately 50 fatalities per annum in the industry (with about 250,000 presently employed).

Sweden

During the conversation at Wire Rope Industries (2000 03 21) it was mentioned that, in Sweden, there is no evaluation of the in-situ conditions of wire ropes using either destructive or non-destructive testing methods. Rather, all inspections are visual, and are directed towards assessing corrosion, elongation, and rope waviness. No mention was made of the successes or failures resulting from this approach.

Australia - New South Wales

In the Guidelines (references) for the province of New South Wales, it is specified that "in general, destructive testing should not be substituted for non-destructive testing because the sample of rope used for destructive testing may not represent the section of rope that has deteriorated the most. Non-destructive testing will give a better indication of the condition of most of the rope. Visual examination needs to be used in addition to testing to ensure ropes remain in a safe condition".

Further, both destructive and non-destructive testing must be performed by an approved testing facility. For drum hoists, destructive tests, on samples cut off from the ends, are performed at least every six months. Further, at the end of the first year of operation sufficient rope must be cut from the conveyance and counterweight ends to enable breaking and elongation tests on that part of the rope that has passed repeatedly over the sheave (Guidelines, p. 47).

For friction winders, it is recommended that destructive tests be performed on a section of rope after the rope has been in service for five years, and then at intervals of three years thereafter. It is noted that this practice may require the use of extra links in order to maintain fixed distances between docking positions. For multiple ropes, "it may be appropriate to test one end of one rope after five years then one end of another rope each three years or less thereafter" (Guidelines, p. 47).

As regards non-destructive testing, it is specified that all new ropes should be tested within four weeks of being placed in service - after the initial stretch has occurred, but before there has been visible wear. Measurements of diameter are also to be made at this time (Guidelines, p. 48).

In connection with non-destructive testing, it is suggested that head ropes should be tested: every six months during the first three years of service, every five months during the fourth year, every four months during the fifth year, and every three months thereafter (Guidelines, p. 49). For balance ropes, the intervals are 12, 10, 8, and 6 months, respectively.

Further, it is noted that the frequency of testing should be increased: (1) if only a single rope is used to transport men; (2) if the permissible factor of safety is being approached; (3) if the maximum life is being approached; (4) if the loss of metallic area exceeds a pre-determined

figure for the rope construction (usually 6%); and, (5) if an anomaly is suspected (Guidelines, p. 49).

Procedures are given to ensure that the operating instructions for the machine are followed and that the work is performed according to appropriate standards. It is noted that NDT instruments should be sufficiently sensitive to detect a change in the metallic area of the rope of 0.5% (Guidelines, p. 50).

In summary, the Guidelines established in New South Wales are both very comprehensive and exacting in the coverage of all of the possible details that surround destructive, non-destructive, and visual examinations, and the maintenance of records.

13. Inspection Practices

During the discussions one point which emerged prominently from all quarters was that there has been a deterioration in the extent to which wire hoisting ropes have been inspected by mine operators. The blunt fact is that, even though the regulations state [Québec, S-2.1, r.19.1, art. 305, 1] that the rope must be inspected at least once every day, and even more thoroughly at least once per week [Québec, S-2.1, r.19.1, art. 305, 2] it was frequently mentioned that this is almost never done according to the intentions behind the regulations – i.e. that there should be a complete and satisfactory visual inspection before the beginning of the daily shifts.

The problem seems to be that either the inspection is cursory, or the speed of the rope is too high to detect anything other than the most major of defects, or the ambient lighting is inadequate, or the physical arrangement for making the inspection is unsatisfactory.

Likewise, the Québec regulations also state that at least every 45 days the cable must be inspected in detail at the points of attachment and at least at one location every 100 metres [Québec, S-2.1, r.19.1, art. 305, 3]. At these locations it is stipulated that the cable must be cleaned, measured for diameter, and examined for broken wires and other defects. This information is intended to be used as a database by which the performance and deterioration of a cable can be checked. It was noted that such information is of no use if it is never used. To illustrate this point, the OMOL staff mentioned that the cable which had failed at the Panel mine had been measured with calipers and that the losses in diameter were clearly shown. Unfortunately, this was not observed and action taken.

In Ontario, the regulations prescribe that wire ropes shall be inspected on daily, monthly, and biannual bases. During the daily inspections "the exterior of each hoisting and tail rope is to be inspected to detect the presence of kinks or other damage and to note the appearance of the rope dressing..."[R.R.O. 1990, Regulation 854, Section 248 (2) a (i)]. During the monthly inspections, the shaft ropes are inspected to determine: the amount of wear, distortion and corrosion [R.R.O. 1990, Regulation 854, Section 248 (2) c (i) A]; the need for lubrication [R.R.O. 1990, Regulation 854, Section 248 (2) c (i) B]; the need for changing the wear patterns [R.R.O. 1990, Regulation 854, Section 248 (2) c (i) C]; and the number and location of broken wires [R.R.O. 1990, Regulation 854, Section 248 (2) c (ii)].

During the biannual inspections, it is the points of attachment to the drum and the conveyance (or counterweight) which are to be inspected [R.R.O. 1990, Regulation 854, Section 248 (2) d].

Notwithstanding these requirements for visual inspections it was frequently mentioned to the writer that these are often not performed to the standards that were once in place.

The reasons for this included the change in culture which is taking place throughout the industry, downsizing, turnover, lack of skilled personnel, and the changing requirements of work. Some recalled former days, when there was a job description for "rigger" and when these people were solely engaged with but one function - maintaining the wire hoisting rope. It was noted that those days have passed and that today, the former functions are but one of those possibly required of a

single person. In short, so much is being demanded of people that one can question whether or not all of it is being done well.

Further, it was noted that cutbacks had resulted in a loss of skilled people with core craft competencies who "knew the rope", and that, in many respects, untrained people were being asked to assume the roles. Additionally, too much is being demanded of people at a time when it is crucial that more attention is paid to the wire rope. If reduced safety factors are to be permitted there must be rigorous daily inspections as well as safety audits to ensure that a process is being followed.

These two factors combined were identified as being the reasons why ropes in North America are not being inspected with the care that should accompany the task. For example, if an attempt is made to inspect the rope at normal hoisting speed very little will be seen except perhaps the major defects (such as a broken strand) for which it must be rejected. The intent behind the regulation is that the rope should be inspected at a reasonably slow speed so that some of the finer defects, such as broken wires and corrosion, may be spotted. This requires time, and mine operators must be prepared to invest it.

In South Africa, on the other hand, it was noted that the "rigger/ropeman" is still very much alive as a job classification and that these people continue to discharge their duties diligently (discussions at Miningtek, 2000 04 11). Parts of their duties should, and do, include going to the winding house (i.e., hoist room) to listen for the noises accompanying winding (pinging, plucking), to look at the rope ends on the drum, and to examine the attachments. It was also noted that the standard speed for rope inspections is 2 m/sec (two metres per second).

In the United States of America the Regulations [57.19023 (a)] require that every wire rope in service shall be inspected along its entire length at least every 14 calendar days. For newly installed ropes or any rope that has not been inspected within the previous 14 days it must be examined before any person can be hoisted [57.19023 (b)]. Further, non-destructive tests must be carried out along the active length of the rope, or rope diameter measurements shall be made: (1) wherever wear is evident; (2) where the hoist rope rests on sheaves at regular stopping points; (3) where the hoist rope leaves the drum at regular stopping points, and; (4) at drum crossover and change-of-layer regions. These measurements are to be made at least every six months [57.19023 (c)]. It was noted in the conversations with MSHA that these readings may be made by the mine staff or by outside contractors. MSHA's role is not to make inspections, except under circumstances where this is requested to provide technical support.

One of the comments that arose in South Africa (Dohm, 2000 04 17) is that there is a need for standards, training, and procedures which can be followed in the world of hoisting. It was noted by several persons in South Africa that, following the development of the SABS Codes as national standards for hoisting practices the next logical step would be to work towards an ISO code (International Standards). The South African Bureau of Standards (SABS) is currently working in this direction. There can be no doubt that globalization brings with it the need for all to be working towards the same ends.

One of the key points that was made in the discussions in South Africa is that it is essential that all parts of the hoisting rope must be inspected every time that there is an inspection. This includes the "back end" of the system, which can easily be neglected. More than one reference was made to near disasters that had taken place for lack of maintenance of the rope at the hawse hole. It is particularly in this area that some of the greatest damage occurs. The "dead coils" on the drum are always at the same location, with the result that the outer wires can be severely worn due to the winding of the loaded rope onto these during hoisting. During unwinding the tension is released and slippage occurs. It was noted that it is crucial that the rope be turned at those times when the rope is pulled through the hawse hole in order to obtain back-end samples.

Failing this, the inevitable result will be that bad turns are placed in the most-loaded part of the rope.

In the United Kingdom, it was noted that the trend has been away from prescriptive regulations, towards operators being required to practice "goal setting" and being monitored for compliance. As has happened in South Africa, and imminently in Québec, the United Kingdom has also involved Codes of Practice into the Regulations (noting that it is much easier and practical to amend and up-date the former than the latter). In any prosecution the Court is provided with both the Regulations and the applicable Codes of Practice, and uses the latter to determine if the former were broken.

In the present regulations, it was said (HSL, 2000 05 24) that "the owner will ensure that a rope is always fit for the duty". In general, wire ropes are approved for use on drum winders for periods of 3.5 years, and on friction winders for periods of two years. The period which is authorized may be extended by an inspector, and subject to such conditions and requirements as may be imposed.

In Poland, the regulations (2.2.2.2., p. 170) specify that ropes used for the hoisting of personnel are to be inspected on a daily basis, and prior to the beginning of operations. During these inspections, it is noted that particular attention should be paid to the symptoms of wear and tear and damage to the rope. These include: "a) the occurrence of deformations, such as: corkscrew turns, tightened loops, narrowings, changes in the arrangement of the strands, etc; b) breakage of wires; c) occurrence of other damage arising during the use of the cables the previous day" (2.2.2.3., p. 170).

More detailed inspections are required on a weekly basis (2.2.2.4., p. 170). In addition to the above, inspectors are required to look for: a) as above; b) loosening of the outside wires; c) concentrations of wire breaks over short segments (one or two "lengths of the pitch of the cable" - lay lengths); d) breaks in internal wires; e)wear and unrolling of external wires; f & g) corrosion of both internal and external wires - the latter to be exposed by cut-out external wires; h) changes in lay length ("length of pitch" in the regulations) or the diameter of the rope; i) broken strands or "liniska (note: the meaning of this term is not known to the writer or translator)" in flat cables; j) damage to the weave of the rope and falling out or loosening of rivets ; k) mechanical damage; l) "mobility of the suspension elements" of ropes and the state of the attachments (2.2.2.4., p. 170).

In particular, it is noted that guide ropes and "fender cables" at the points in the shaft where air either enters or exits should be examined for corrosion. Likewise, these ropes should also be examined for wear at those locations where mechanical devices are used to stabilize skips during either loading or unloading (2.2.2.4., p. 170).

In addition, even more extensive inspections are made every six weeks. During the "*six-week inspection*" all of the above are examined as well as measurements of the "Pitch" and diameter of the rope at 50 metre intervals. It is added that the results of these measurements must be entered in "the book of the periodic tests of the hoist installations" (2.2.2.5., p. 170).

As regards record-keeping, the regulations require that documentation must be maintained in respect of every wire rope in service. These records are to contain records of all of the changes noted, indicated through inspections and tests, that have taken place during the period that the wire rope is in service. In particular, the records must contain: "a) a sheet on the distribution of breaks in the wires and damage to the cable; b) a sheet on the results of tests on the cable regarding stretching, bending and twisting of the wires; c) a graph of the accretion of breaks in the wires; d) a graph of the lengthening of the cable" (2.2.2.6., pp. 170-171). Breaks in the wires and other damage noted should also be entered into the records (2.2.2.7, p. 171).

Interestingly, the regulations also specify that, before any rope is inspected, the inspector must review, in detail, all of the records compiled to that date for the rope (2.2.2.8., p. 171).

In Hungary (Geller et al., p-B22), a "Code of Practice" lists a number of performance requirements for acceptable electromagnetic instruments. These are: (1) prior to the performance of testing, the instrument must be calibrated using a bench sample of rope which is of the same size and construction as the rope to be tested in-site; (2) testing must be repeated at least twice, with the same settings of the instrument; (3) the testing of wire ropes and the evaluation of the instrument charts must be performed by the same operator, and; (4) the minimum distance between distinguishable defects in the wire rope must not exceed the diameter of the rope. The criteria for discarding wire ropes in Poland are contained elsewhere in this report.

14. Continuous Monitoring

Throughout this report extensive reference is made to the new Codes of Practice which have been developed and which are being implemented in the Republic of South Africa. In essence, these permit reductions in the design factors which have traditionally been a part of hoisting plant design. This is only made possible, however, by strictly controlling those factors which can cause wear and damage to the wire ropes. There is a strong belief that even though the optic from abroad may be that safety factors are being reduced, the facts are that the improved hoisting practices will considerably improve safety.

In the draft document "Code of Practice, Performance, Operation, Testing and Maintenance of Drum Winders Relating to Rope Safety", to be known as SABS 0294, several stipulations are made for the operating practices which are mandatory for those operating Class 1 hoisting plants. In addition to controlling the dynamic stresses induced through braking, acceleration and deceleration, and loading, it is also required that both the load on the rope and the condition of the rope must be monitored continuously. In the Elandsrand experiment it was reported that the directive had been that, if monitoring ceased the hoist would stop. Provision is being made in the design of these advanced systems to include contacts and alarms that will do precisely that - to cause hoisting to cease if the instrumentation detects either bad practices (through excessive loads) or an indication of problems with the rope.

This is a critical issue since the economic impact of a hoist shutdown would be tremendous.

It is to be stressed that the present levels of technology are such that there are few limitations on designing fully-automated and highly-instrumented mine hoisting systems. In many respects, the technology for continuous monitoring together with built in alarms and safety measures is available. Of concern, however, are the situations which can arise when some small components of such systems fail. Hoist braking systems, for example, operate under conditions of back pressure which is regulated by governors. The failure of a governor (Lilly controller) can cause the systems to fail with resultant enormous dynamic loads being applied to the cable. In the extreme, unpredicted emergency braking can, and has, broken ropes. Thus, automated systems require considerable thought to ensure that unanticipated failures of components will not result in catastrophic damage to the hoisting plant (Albert, 2000 05 05).

The loads on hoisting ropes can be detected through load cells which are mounted near the sheaves in the headframe. Likewise, the condition of the rope can be indicated by passing the rope through the electromagnetic field of a non-destructive testing sensor. In order to eliminate the problems that would be caused by oscillations of the hoisting cable this sensor must be mounted as close as possible to the point at which the cable passes onto the sheave. Further, it must be possible for one to detect defects in the cable at the full operating speeds of 19 metres/second.

During the writer's visits some mention was made of the problems that might result from broken wires passing through the sensor heads. In personal communications with Largo Albert it was understood that several test machines were lost at INCO as the result of broken wires snagging the test heads and pulling these off their moorings - even at low rope speeds of 100 feet

per minute. The staff of Rotesco, however (2000 09 07), indicated that serious damage to the test heads because of broken wires had only occurred two or three times in the past five years. The opinion was that the problem was not sufficiently serious as to preclude the possibilities of continuous condition monitoring.

Thus, because the accuracy of electromagnetic non-destructive testing devices decreases as the air gap between the sensor head and the cable increases, the design of continuous monitoring systems is a critical issue. Albert (personal communication) was of the opinion that such devices should be mounted as close as possible to the drum - where "rope whip" is at a minimum.

The South African Codes of Practice also specify that the stresses in a wire rope must not exceed 40% of the ultimate breaking strength of the rope. If this happens, it is required that an immediate non-destructive test be performed in order to assess if the rope has suffered damage. It was stressed in a conversation (Van Zyl, 2000 04 18) that, while the limit of permissible stress is specified, the means by which this must be achieved are not. Thus, closed-loop braking systems are not mandatory. Mine operators are free to choose the options that they will employ in order to keep stress in the rope under control.

Another condition which must be detected is the onset of slack in a mine hoisting rope. The writer was told (2000 04 18) that this has become a daily occurrence in South African mines as the country's operators introduce hydraulic clamping of conveyances in deep shafts (over 1500 metres, or about 4900 feet).

Other conditions which must be detected include: (1) too few turns of rope remaining on the drum; (2) limitations on speed; (3) over-winding men; (4) over-winding materials. An ultimate trip switch must also be provided.

Finally, an important point that was made in the conversations at the South African Bureau of Standards (2000 04 18) is that adequate redundancy must be provided in all automated monitoring systems. Inasmuch as the mine's production ceases if the hoisting system stops, there must be adequate safeguards to ensure that the cause of any stoppage is due to the condition of the hoist/wire rope and not due to failure of the instrumentation. It is considered essential that emergency backup of power should be provided by batteries and that the capacity should be adequate to maintain hoisting operations for at least ten minutes (Van Zyl, 2000 04 18).

As a final observation, it was mentioned during the writer s visit to Rotesco (2000 09 07) that the company had long-advocated a research project on continuous rope condition monitoring but had been unable to recruit an industrial partner.

15. The Criteria for Rope Replacement - the Practices in Key Jurisdictions

At the outset of this section it must be mentioned that National Standards have been developed for the destructive testing of wire ropes, and are now being developed for non-destructive testing and Mine Hoist Rope Removal Criteria (CSA G4). The reasons for this are that, while there is only one laboratory in Canada which is presently being used by the entire Canadian mining industry for destructive testing, namely the Materials Testing Laboratory of the Ontario Ministry of Labour, at Sudbury, it is conceivable that other players could enter the picture in the not-too-distant future. In part, this could be driven by the Ministry's oft-expressed desire to privatize their laboratory, which is viewed by some as a commercial operation and not directly relevant to the core of their business or "raison d'être". In part, it could be driven by others wishing to offer their capabilities in the Free Trade environment. At present, OMOL's laboratory is the only CSA G4 certified facility in the country.

As concerns non-destructive testing, there are presently several firms which manufacture and market instrumentation and which offer testing and inspection services to the mining industry. Once again, in the Free Trade environment of the global economy, it is very likely that others may choose to enter the Canadian scene.

With that as background, it becomes very important that there should be well-defined standards which must be followed by all participants. It is a critical issue that all test results should have the same meaning, regardless of who has performed the test. National standards are essential.

For those reasons Canadian Standards Association CSA G4 has been developed as the National Standard. It has been said to be more rigorous than the regulations require in any of the Canadian jurisdictions (OMOL). When adopted, it will preclude the possibility of there being a number of independent testing laboratories all testing differently (dimensions of samples, rates of loading, etc.). In essence, all concerned will be compelled to "sing from the same songbook".

Traditionally, wire rope manufacturers supply a certificate attesting to the strength of a wire rope when it is delivered to the customer. The impact of the Standard, if specified that ropes delivered must be tested in accordance with it, will be that there will be no ambiguity among the results.

Also as concerns destructive testing, it must be acknowledged that the pull test by which a sample of wire rope is extended to destruction is by no means the only test which is performed.

In Ontario, the practice is to determine the extension which takes place during the pull test as well as the ultimate breaking strength. This provides a measure of the elasticity of the rope and when the yield point is attained. It is a measure of the resilience of the rope and the amount of strain energy which can be absorbed by it.

In Europe, it is understood that "aggregate testing" is the norm. In this method, pull tests are performed on individual wires which represent samples of the various wires used in the construction of the rope. The results are then "aggregated" in order to calculate the theoretical strength of the rope as a whole. As will be noted, one of the difficulties of this is that the

"spinning losses" (i.e. the reductions in strength caused by winding the wires and strands upon each other during the construction of the rope) are not included.

In Germany, Gronau (2000 05 29) advised the writer that the ultimate tensile strength is calculated by multiplying the calculated aggregate strength by a factor which varies from 0.7 to 0.9, depending on the rope construction. The aggregate strength is used to calculate the static safety factors at the time of installation of any new rope on a hoist. It is to be noted that most hoists are of the friction variety.

At one time, there was a requirement that destructive tests be performed on all ropes that had been discarded. The purpose was to correlate the loss in strength with the observed conditions in the rope. It was understood that this requirement was abolished in the mid-1990s.

For a variety of reasons, OMOL's Sudbury laboratory does not perform aggregate testing at present. While some aggregate testing has been performed in the past, the view of OMOL is that more research is required before proper rope retirement criteria can be established.

An important point is that, regardless of which method is used, the results to be compared must have been obtained through similar means. Destructive test results must be compared with the same, and this applies also to the results of aggregate testing.

Next, destructive tests also involve both torsion tests and the disassembly of the uppermost one-foot sample of the rope to which reference has already been made. The former permits an assessment of the ductility of the wires in the sample while the latter permits a detailed examination of the internal condition of the rope. Since there is no other means of determining the internal condition of a rope the disassembly is perhaps one of the most valuable tests of them all! Through it, the quality of the dressing and the lubrication of the rope can be assessed, as can any damage that has taken place through corrosion.

Finally, and particularly during the discussions at NIOSH (2000 04 04), it was stressed that the criteria for rope removal which are used in the many jurisdictions in North America do not correlate with each other either for the same rope or for different ropes. The regulations in North America have been written generically for "rope" irrespective of the several different constructions which are now found. Using one example for a 6X25 Filler Wire rope, it was demonstrated that a 5% loss of diameter of the rope would also be accompanied by about a 3% Loss in Metallic Area and a 40% loss in the diameter of the outer wires. Thus, against the background that a 1/3 loss in diameter of the crown wires is also a criterion for removal, the rope should probably be rejected at a corresponding loss of diameter of 4% (McKewan). It was stated that there is a need to ensure that the removal criteria match up for the various rope constructions.

A notable example is that, at present, the same criteria apply to both round-strand and flattened-strand constructions, which are entirely different.

Both before and during the visit to South Africa, the writer had the opportunity to make extensive study of the new South African Bureau of Standards Code SABS 1996:0293

"Condition Assessment of Steel Wire Ropes on Mine Winders". In it, several leading-edge changes to the thinking on wire rope retirement criteria have been made. In the writer's opinion, the most important of these is the recognition that not all ropes are alike and that there must be different criteria developed for each of the various wire rope constructions, During the author's visits, there was not a single person who disagreed with this. In the South African Code it is also recognized that the distribution of the wires that are broken, in any given length of rope, is important. There are enormous implications as regards the strength remaining if all of the wires broken are concentrated in one area of the rope, or in one or two strands, or are concentrated in either the core or the crown.

In the United Kingdom, wire ropes are generally approved for service on drum hoists for a period of 3.5 years, and on friction hoists for periods of two years. These can be extended for as long as deemed safe by an inspector, and subject to such terms and conditions as may be required. While this seems "looser" than the practices in other jurisdictions, it must be borne in mind that the Safety Factors are much higher, mines are much shallower and much fewer in number, and corrosion virtually unknown. It was noted that a winding rope has not broken in service in the United Kingdom since 1965.

In Poland, the regulations specify that "If, on the basis of inspections and tests carried out, it is suspected that the hoist cable does not conform with the regulations of decree § 552 and the present appendix, a special testing of the cable should be carried out by an expert, or the cable should be replaced" (2.2.2.9., p. 171).

A. Destructive Tests (in which samples of rope are tested to failure)

1) Loss of Breaking Strength (LBS):

The Regulations in the Provinces of Ontario and Québec specify that a hoisting rope or a multi-layer, multi-strand balance rope shall be rejected when a loss of 10% of the original breaking strength has been detected in any part of it [R.R.O. 1990, Regulation 854, Section 228, (18) 1 & 2][Québec S-2.1, r. 19.1 a. 293, 3]. Single-layer, single-stranded balance ropes are to be rejected when the strength has dropped by 15% [(18) 3], while guide or rubbing ropes are to be discarded when the strength has dropped by 25% [18 (4)].These losses are detected through tensile tests to destruction of sample pieces of the rope. The samples are obtained from above the attachment of the rope to the conveyance.

In Ontario, the regulations specify that destructive tests must be performed not more than six months after the rope has been placed in service and at intervals of six months thereafter [R.R.O. 1990, Regulation 854, Section 228 (2)]. The practice is slightly different in Québec, where it is specified that the initial test must be performed within 12 months of installation [Québec, S-2.1, r.19.1, a. 295, 1], and, if a loss of strength greater than 6% is detected, the frequency of testing must be reduced to every three months [Québec, S-2.1, r. 19-1, a. 295, 1]. It was mentioned (OMOL, 2000 03 29) that previously the regulations had specified that tests should be performed every eighteen months. In the light of the rapid deterioration of some ropes, however, it was decided to reduce the time between tests in order to preclude possible failures caused by high wear. Notwithstanding this, it is noted that recently a six-month-old rope failed at

Agnico Eagle's Laronde mine, in northwestern Québec. The cause was exceedingly rapid corrosion at the cappel due to acid mine waters.

Québec also specifies that when a rope is supplied to a mine it must be accompanied by a manufacturer's certificate on which are stated all of the details of its construction and manufacture together with the results of torsion and tensile testing for a sample of the wire used as well as tensile testing for a sample of the whole rope [Québec, S-2.1, r. 19.1, arts. 284, 12-13, 285]. This requirement, however, while being contained in CSA G4, has not been enacted in the various Mining Health and Safety Acts across the country. It was suggested strongly that it should be (OMOL).

In the United States of America, the Regulations (57.19024 (h)) state that a wire rope shall be retired from service when there has been a loss of more than 10% of rope strength as determined by non-destructive testing. It is to be noted that destructive testing is not required in the USA and that losses of rope strength are all "determined" ("estimated" would be a better word) from NDT methods.

In the South African new Code of Practice (SABS 0293:1996), it is stated that "where breaking strength tests are carried out on rope samples adjacent to the termination, the rope shall be discarded when the breaking strength is less that 90% of the breaking strength of the new rope (5.12.1).

In the United Kingdom, it is also specified (in the Code of Practice) that the wire rope shall be discarded when the loss of breaking strength has exceeded 10%.

In Poland, the regulations specify that hoist ropes must be subjected to testing by all available methods after a year of operation. The period is extended to 1.5 years in the case of both round and flat balance ropes (2.2.2.15., p. 171). For drum hoists, a 1 metre segment of the cable must be cut out and subjected to strength tests at least every twelve months. If the rope is more than two years old, however, the frequency is increased to strength determinations every six months (2.2.2.16., p. 171). In the conversations (2000 06 01), it was noted that ropes are rejected when the loss of breaking strength exceeds 15%. This was thought to be equivalent to a 20% loss of metallic area, and it was stated that both figures should probably be reduced by 5%, to values of 10% (for LBS), and 15% (for LMA), respectively.

In the Australian province of New South Wales destructive testing is required and, as elsewhere, ropes should be discarded if the loss of breaking strength exceeds 10% (Guidelines, p. 57).

In Ontario, the samples are obtained from a 2.5 metre length of rope [R.R.O. 1990, Regulation 854, Section 228, (1) a] which is cut from immediately above the cappel once the conveyance has been secured and the mechanical attachment disconnected. OMOL staff (2000 03 29) mentioned that the Regulations once required that a ten-foot section above the cappel must be discarded every six months, since that part of the rope, immediately at the top of the cappel has been observed through practice to exhibit the greatest damage. Due to flexion, 40% losses of breaking strength have been determined at this location.

The old practice is no longer required, however, since the regulations presently specify that destructive tests must be performed at the same frequency [R.R.O. 1990, Regulation 854, Section 228, (2)]. Nonetheless, it was understood that mine operators continue to cut off lengths longer than that required for testing in order to discard lengths of the most severely damaged rope in the shaft.

It was noted (Falconbridge) that approximately six hours is required of a team of five persons to perform all of the operations of disconnecting the rope, cutting the length required, and reattaching the conveyance. This probably costs the mine operator at least thirty man-hours of labour together with the value of lost production and services. Against this background, the incremental costs of performing destructive tests were thought to be moderate.

During the testing procedures, and subsequent to cutting the sample for destructive testing from the rope in the shaft, short sections are cut from either end. This is an important step, since, as noted, the lowermost piece has been noted as being exceptionally damaged and, therefore, not necessarily representative of the rope above.

Similar procedures are followed in other countries, but it is noted that shorter samples, six feet, are used in the United Kingdom.

During the conversations there was a spectrum of opinion concerning whether or not the section of wire rope immediately above the cappel is, in fact, the most damaged piece of rope in the shaft. An argument can be made that the point of maximum stress will be at the top of the sheave wheel when the full length of the rope, the conveyance, and the payload, are suspended below. Nonetheless, the loss of metallic area due to corrosion is considered to cause the worst damage to wire hoisting rope, and thus, for the moment, obtaining samples at the cappel is considered to be the most logical (after all, one can not obtain a sample from mid-rope without destroying the rope!). Delorme, in another conversation, (2000 03 22) mentioned that corrosion is the ultimate cause of rejecting 80% of the ropes which fail destructive tests, and which are scrapped.

Another concern that was raised is the time that passes between obtaining the sample for destructive tests, the actual testing, and the final replacement of the rope - if required. It is conceivable that the entire process could require several weeks. The implications of a failing test, therefore, can be that a rope which should have been removed on the day in which the sample was obtained has been in service ever since and very likely becoming in even worsened condition. In this respect, the safety factors are comforting.

Nonetheless, the industry is taking measures to ensure that ropes are replaced without delay whenever this is required. In South Africa, for example, it is required that a spare rope be on hand at the shaft. Under these circumstances, the replacement of a defective rope could be effected very quickly.

In Canada, there are presently no equivalent requirements. Nonetheless, it was mentioned that several operators do have spare ropes on hand and that, in Saskatchewan, where several similar operations are close by it is customary that a "universal spare" be available to meet the urgent needs of a group of mines (Steve Wood, Wire Rope Industries, 2000 03 21).

INCO, in Sudbury (2000 03 28) stressed that it has developed its own Guidelines and that these exceed the present Ontario requirements. For example, if a 10% loss of breaking strength is reported as the result of a destructive test and if there is no reason to suspect that the test may have been questionable (and it was noted that this is not unknown, but rare) the rope is removed immediately and no further use is permitted. If, however, it is suspected that the test may have been inaccurate a further sample is obtained and tested. In the meantime, until successful results have been obtained, the rope is out-of-service.

Additionally, it is considered that the loss of strength by a rope is very rapid after a 6% loss has been detected (CTN Meeting, 2000 02 04). In Ontario, the practice is that a Cautionary Advisory is issued to the mine operator once a 6% loss of breaking strength has been observed. It was noted, however, that the present Regulations are a bit "on-off" inasmuch as a 9.9% loss is acceptable but 10% is not. As noted, the same practice is followed in Québec [Québec S-2.1, r.19.1, art. 295, 1].

As regards the value of destructive tests there has been a unanimity of view in Canada, South Africa, and the United Kingdom, that the state of the art of non-destructive tests has not yet advanced to the point at which destructive tests can be eliminated. It was noted that all of the criteria have been developed as the result of specific problems that have occurred and that each indicates something different about the condition of the rope. Delorme (2000 03 22) noted that the test after installation provides a reference datum which would otherwise not be available and that this is an opportunity to detect broken wires that might have been theretofore unobserved. INCO staff (2000 03 28) reinforced this point and added that the test probably indicates what form future fractures will take. It was noted that determinations of the strength of the rope after it has been placed in service is not available in any other way.

Interestingly, the point of view of NIOSH staff was the exact opposite. Destructive tests are not required in the United States of America and the strength of the rope, apart from the original manufacturer's certificate, is estimated through non-destructive testing methods. It was noted that destructive tests had been performed on cutoffs (at the USBM) for many years and that no differences from the original strength was noted unless there had been corrosion. It was also noted that American mines are "dry" mines. When the writer added that cutoffs are required in Ontario to address the problem of fatigue at the cappel/rope contact the view was that this is a perfectly valid reason to remove a section of the rope but that this was for a completely different reason - to address a problem of flexion.

In the conversation it was also noted that the sections of rope which are removed periodically, while having been subjected to corrosion and flexion have never been subjected to wear. It was noted that the worst damage to a rope, through crushing, probably occurs at its contact with the drum when a skip is being loaded. This point has been addressed in the new South African Code of Practice, which will be discussed shortly.

In the case of destructive tests the view of Canadians is that these should be viewed as a suite comprising determinations of loss of tensile strength, extension (or strain), and torsion. Each indicates something which can not be determined in any other way.

For example, the destructive tensile test indicates not only the loss of strength which may have taken place as the result of use but also the mode of failure that is likely to result in time. A ductile failure in the test is regarded as indicating the occurrence of strain aging in the wire rope - a rapid process of deterioration which can not be detected by any other means.

In the United Kingdom, it was noted that there still are too many unknowns in the domain of non-destructive testing and, thus, destructive tests (including the full suite of disassembly, torsion tests, and complete inspection and evaluation) continue to be essential (HSL, 2000 05 24).

In Europe, "aggregate testing" of the individual wires of a rope takes the place of our tensile test of the whole rope (OMOL 2000 03 29). The comparison of the ultimate strength of the aggregated wires and strands and that of the constructed rope is not as simple as it appears to be at first glance, however, since the result for the aggregation must be reduced by a percentage (which varies) to compensate for "spinning losses" of strength. In effect, winding the wires together into a rope causes sufficient damage to the wires and strands that this is reflected in a loss of the total strength of all of the wires added together. It was emphasized that exact comparisons between aggregated or whole rope test results are not possible and that any attempt to do so should be avoided. Rather one should always compare the initial and subsequent test results according to the testing method used. In general, the losses should be about the same regardless of the method used.

During the discussions in North America, however, it was considered that the aggregate test is of very limited value and should not be used except for a rope which is being placed in stationary use and which will never be tested again - such as in a suspension bridge (INCO). The reason for this was stated as being that very small differences in the results for individual wires can be aggregated into very different final results.

In South Africa (Dohm & Borello, 2000 04 17) very strong views were expressed that the breaking strength test is indispensable and can not be replaced by any other means of evaluation. Martin Dohm noted that the results of these tests are the only absolute values that we have concerning the in-situ condition of a wire rope. Michele (Mike) Borello stated that he is not in favour of aggregate testing for any ropes since he does not consider that these are a true representation of the strength of the rope at all. He added that the results are bad enough for a new rope and probably totally misleading for a used rope. He added that "the results are dubious at the beginning (i.e., a new rope) and become progressively worse".

When questioned on this point, he noted that most hoists in Europe are friction hoists and that it is impossible to obtain samples for destructive tests in the first place. Secondly, most mines are shallow and the safety factors very high, so that a 10% error in the breaking strength as calculated from the aggregate test would be of no consequence. Finally, he noted that large testing machines are not required if only the aggregate test is performed. Thus, there are significant savings in the costs of providing laboratory facilities.

Nonetheless, in Germany, the aggregate method is used and is considered to be very satisfactory. It was acknowledged that while ultimate strength may be calculated by reducing the aggregate

strength by from 10% to 30% - to compensate for spinning losses, depending on the construction of the rope - the discard criteria are worded in terms of losses of strength as calculated by the aggregate method.

Thus, in Germany, it is stated that a hoisting rope which is used to transport workers shall be discarded when the original breaking strength as calculated by the aggregate method has been reduced by 15% (Bellman-Verlag, Dortmund, publication number 455, Section 17.1). When a rope has lost 15% of its strength, and workers are transported, the inspector can authorize its use for longer periods (Bellman-Verlag, Dortmund, publication number 455, Section 17.2). For ropes which are used to hoist the clam on shaft-sinking operations the 15% loss criterion applies (Bellman-Verlag, Dortmund, publication number 455, Section 17.3). For balance ropes on friction hoists , the loss of strength permitted is 30%, but, in no case must the factor of safety have been reduced to less than 5 (Bellman-Verlag, Dortmund, publication number 455, Section 17.4). Finally, for guide ropes, the ropes must be discarded when the loss of metallic area of the outer wires has exceeded 40% (Bellman-Verlag, Dortmund, publication number 455, Section 17.5 (b)), or when the loss of strength has exceeded 15% (Bellman-Verlag, Dortmund, publication number 455, Section 17.5 (c)).

Finally, in Canada, because of efforts to resist the corrosive action of acid mine waters, galvanized hoisting rope is becoming much more common. It was noted that galvanized rope is very much the common rope in South Africa and is used almost exclusively (INCO 2000 03 28). At present, it was understood by the writer that INCO is in the process of replacing all of its ropes that are being taken out of service with galvanized stranded ropes. The intention is that 100% of its ropes shall be corrosion-resistant.

A key point in this is that galvanized rope stretches and seats itself when placed in service. Thus, the benchmark for determining the changes which have occurred before subsequent tests is not the initial test but, rather, the first test that is made after the rope has been in service for six months.

According to Bill McKewan, NIOSH (2000 03 20), none of these subsequent test values have ever been less than the original. If that is the case, what is the value of these tests? In a conversation with Steve Wood and René Sallafranque, at Wire Rope Industries (2000 03 21), however, it was stressed that the samples tested are from that part of the rope which is considered to be possibly in the worst condition - namely, at the attachment of the rope to the conveyance, where corrosion would be the worst. The tensile test, and the accompanying torsion test, therefore, continue to be valuable in the respect that the effects of internal corrosion are detected where it is undetectable by any other present means.

At the risk of repetition, then, it was emphasized during the visit to the Health and Safety Laboratory, in Sheffield, United Kingdom (2000 05 25) that "a critical point is that the state-of-the-art in non-destructive testing is presently such that destructive testing, and all of its aspects, including disassembly, continues to be essential in order to determine the loss of strength in wire rope. This is absolutely necessary". Additionally, it was emphasized that the cutting of end samples involves not only a complete inspection of the rope removed but also the opportunity to re-terminate that part of the hoist rope which has suffered axial fatigue damage.

As a point for future research, it was observed that the uniaxial tensile test could be improved through adding to the test sample a state of torsion which replicates that in the wire rope from which it was removed (Chaplin, 2000 05 25).

Next, in the Australian Province of New South Wales destructive testing is required. As elsewhere, ropes are to be discarded when the loss of the original breaking strength, at the time of installation, exceeds 10% (Guidelines, p. 57).

2) Reduction in Extension during the Tensile Destructive Test:

Once a wire rope has been placed in service work hardening takes place and the rope becomes stiffer. This results in the stress-strain curve becoming more linear, with less permanent deformation before failure.

The Ontario Regulations [R.R.O. 1990, Regulation 854, Section 228, (19) a] state that a rope shall be rejected when the extension of a test piece during a tension test has decreased to less than 60% of its original extension when tested to destruction.

During use, work hardening of the metal takes place and the wires become brittle. When the extension during a subsequent test has decreased to about 60% of the extension in the original test the interpretation is that there has been a reduction in the yield point of the rope.

In the South African Code of Practice SABS 0293:1996, it is stated that "where breaking strength tests are carried out on rope samples adjacent to the termination, the rope shall be discarded when the plastic strain (plastic fraction of elongation per unit length of rope) is equal to or less than 0.5% (5.12.2). It was noted (discussions at Miningtek) that the plastic fraction of deformation normally starts off at about 2.5% to 3% when the rope is new, and depending upon the type of construction.

Likewise, in the New South Wales Guidelines (p. 57) it is specified that the rope shall be discarded when "the elongation is reduced to less than 60% of the original as obtained by destructive test (sic)" and if there has been either excessive rope stretch or a rapid increase in the stretch.

A singularly important point that was made concerning strength tests (Chaplin, 2000 05 25), is that the object of these is not to show that the rope is dangerous, but, rather, that the rate of change in the loss of strength is becoming dangerous. Previous reference has been made to the fact that loss of strength accelerates very quickly after about 12%. Thus, once 10% has been attained it is certain that the rope is becoming short-lived.

3) Total Extension:

During the conversations in the United Kingdom (Chaplin, 2000 05 25), it was mentioned that the old practice in Belgium once involved discarding ropes based on the total extension that had taken place (expressed as a percentage).

4) Reduced Wire Torsion Turns:

The Ontario Regulations [R.R.O. 1990, Regulation 854, Section 228, (19) a] also state that a rope shall be rejected where "the extension of a test piece has decreased to less than 60 per cent (sic) of its original extension when tested to destruction and marked corrosion or considerable loss in wire torsions has occurred". The discard criterion is when the number of turns to failure has been reduced to 15% of that observed in the original test. This test is performed concurrently with the tensile test. Work hardening results in the wires becoming brittle, and, thus, the number of turns in the torsion test is reduced. Corrosion pits and wire nicking also influence the results.

The torsion test indicates the ductility of new wires. Once the rope has been in service any interstrand nicking or corrosion will result in "stress risers" which will cause the number of turns to failure to be reduced. In effect, the torsion test accentuates the results of any defects in the rope. The causes must be established through visual examinations. In discussions at NIOSH (2000 04 04), it was mentioned that wire loses its resistance to torsion rapidly once it has been placed in service and subjected to work-hardening. It was noted that 15 to 20 turns are normal in the initial test but that one is lucky to obtain two thereafter!

In CSA G4 it is also recommended that the rope should be rejected when the turns to failure have been reduced to 15% of those observed during the original test. It is added, however, that the rope should be removed within 7 days and that the load on the rope and the speed to which it is subjected may be reduced (depending on other factors). INCO (2000 03 28) noted that it operates in accordance with these recommendations.

It is to be noted that torsion tests are not performed in Europe, but, rather, bending tests are used (OMOL 2000 03 29).

5) Disassembly:

Throughout the world it is common practice for rope to be tested periodically through controlled disassembling of samples. In this way, and only in this way, is it possible for skilled persons to look inside the fabric of a rope and to examine features such as: the presence of interstrand nicking and broken wires; the extent to which the rope is corroded; the quality of the lubrication and the dressing; and the condition of the core. It has been mentioned that there is simply no substitute for this examination (OMOL).

During the visit to CSIR's Miningtek, in Johannesburg, it was observed that an equivalent practice is followed following the completion of destructive tensile tests. At that time, the broken ropes are examined carefully with a view towards determining the types of fractures of the wires and the internal conditions of the rope. Corrosion was stated as being a relatively rare cause of deterioration.

During the visit to the Health and Safety Laboratory, in Sheffield, England (200 05 24) it was stated that disassembly of samples of wire rope cut from the ends is absolutely essential as a means of assessing the internal condition of the rope. In the case of shallower shafts it was noted that the potential concern is not so much with broken wires, but, rather, with corrosion. In order

to determine this a disassembly of a sample is essential. It was also noted that locked coil rope is common in Great Britain and that, in such ropes, corrosion usually takes place between the centre and the adjacent covering layer. This can not be seen through visual inspections or with certainty through electromagnetic methods.

B. Non-Destructive Tests (in which the structure of the rope is not affected)

6) Increase in Extension During Service:

This is not presently a criterion, but while some have suggested that it should be considered for inclusion, others question its usefulness (Albert, communication).

7) Loss of Metallic Area (LMA):

A loss of metallic area indicates that the rope has been reduced in cross-section and has lost part of its load-bearing capacity. In the discussions it was generally agreed that there is a loose correlation between LMA and loss of breaking strength (LBS) but that this is imprecise. In the opinion of NIOSH staff (2000 04 04), however, it was stated that a loss of metallic area of 10% means that the rope has certainly lost a significant part of its breaking strength and is probably in very dangerous condition. In theoretical calculations, it was established that for a 10% loss in LMA the rope would have lost almost 10% of its diameter and 70% of the diameter of its outer wires. In all likelihood it would have been rejected a long time previously on the basis of failing either or both of these latter criteria.

This point was also discussed during the writer's visit to Rotesco (2000 09 07). It was noted that there is a need to establish the relationships between LBS and LMA for the various rope constructions, and the mechanisms of deterioration.

In Ontario it is specified that a rope shall be rejected when it has been determined through an electromagnetic test that there has been a loss of breaking strength that exceeds 10% [R.R.O. 1990, Regulation 854, Section 228, (4) c]. Further it is required that such tests be performed within six months of the rope being placed in service and at intervals not exceeding four months thereafter [R.R.O. 1990, Regulation 854, Section 228, (4) b]. Further, this interval may be reduced when it can be inferred that the loss of breaking strength will exceed 10% before the next test would be scheduled to be performed [R. R. O, Regulation 854, Section 228, (4) c].

In Québec, all ropes used in shafts must be subjected to electromagnetic tests. For hoisting cables the tests must be performed at least every six months. If it happens that a loss of metallic cross-section of greater than 6% is detected, this period must be reduced to no more than every three months [Québec, S-2.1, r. 19.1, art. 295, 3]. This also applies to the hoisting ropes used on friction hoists. As regards balance ropes, the criteria are that pre-formed and non-preformed cables must be replaced when the losses are 12% and 25%, respectively [Québec, S-2.1, r. 19.1, art. 293, 4]. Finally, rubbing ropes ("cables de frottement") must be replaced when a loss of section of 25% has been detected at any point along the rope [Québec, S-2.1, r. 19.1, art. 293, 4].

Not all ropes are equal, however, as there are several different constructions now in use in Canada. One observation (INCO) was that it is very hard to detect cross wire nicking in non-rotating ropes. These can cause severe damage to the interior of the rope, which can not be detected by electromagnetic methods. The staff at Falconbridge (2000 03 28) noted that the use of non-rotating ropes during the sinking of the proposed Onaping Deep shaft (8600 feet) would present difficulties in the use of electromagnetic methods of inspection. In South Africa (discussions at Miningtek) it was noted that non-destructive methods are "not so good" for determining the in-situ conditions of non-spin ropes (because of the tight construction) but are reasonably good in indicating the strength losses due to corrosion (it is to be noted that the products of corrosion are also ferromagnetic). For locked coil ropes, however, the instruments were thought to be inapplicable.

In the United States of America, MSHA generally recommends to an operator that plans should be made to acquire a new rope once the loss of breaking strength, as estimated from LMA measurements, has attained 8%. This is similar to the provision in the new CSA G4 document to the effect that plans should be made to remove the rope soon once the loss of breaking strength through LMA measurements has been determined to be in the range of 8% to 10%. Going farther, however, a removal within seven days is recommended when the loss is in the 10%-12% range , and immediate removal indicated when it exceeds 12%. It is to be noted that, in the draft CSA document, the loss is not clearly specified as a loss of strength as estimated through electromagnetic measurements.

All of these above figures are assumed by this writer to be the <u>percentage losses of strength as estimated through LMA</u> measurements. This is not made clear in some regulations, however, and action should be taken to eliminate any ambiguities. In the Québec regulations, for example, the wording used is "perte de section", where perhaps "perte de teneur" would be more appropriate to the intent [Québec, S 2-1, r. 19.1, art. 293, (3)-(4)).

In all instances it is recommended that hoist ropes must be examined carefully in the areas where losses of metal are indicated. Diameter measurements are recommended, and these are to be compared with previous determinations. Additionally, the lay length is to be measured, the crown wires examined, the broken wires to be identified, counted and examined, and evidence sought in respect of pitting and corrosion. In effect, the rope is to be examined in the light of several criteria and a judgement to be made on the basis of all of the combined findings. It was noted (INCO) that ropes are usually rejected not on the basis of a single criterion, but, rather, on the basis of combined factors.

These losses are generally determined through electromagnetic non-destructive testing methods. In principle, the methods consist of determining the flux both in and around the cable as it is passed through an electromagnetic field. One point of importance, however, is that the evidence suggests that the saturation flux in steel is a function of the tensile stress which is applied to it (Chaplin, 2000 05 25). Thus, while a long wire rope is being evaluated the differences in tensile stress could cause a drift in the integration of the data by the instrument. This could result in the interpretation that there has been an apparent change in the diameter of the rope, while, in actual practice, the change is due to the state of stress in the rope and its influence on flux. There needs to be some research on this point.

Historically, the first instruments used were based on alternating current. The problem with these, however, was that the rope being tested becomes magnetized and must be de-gaussed (de-magnetized) periodically. Further, the procedure is relatively slow, with the recommended speed of the rope between the test heads being 25 feet/minute. At that rate, 3000 foot rope would require two hours for an inspection. It was noted during the visit to South Africa (discussions at Miningtek) that it would be logistically impossible to examine all of the ropes in some shafts at these speeds!

To the writer's knowledge there is but one AC instrument still in use in Canada today, and that is at INCO's Sudbury Operations. The instrument provides but a single trace in respect of the cross-sectional area of the rope that is being passed through it. It is not possible for one to count the broken wires using this instrument. During the discussions with INCO officials (2000 03 28) it was mentioned that plans are being made to replace the instrument and that studies are being made of the advantages and dis-advantages of the possible choices.

The newer generation of Electromagnetic testers are based on Direct Current. There are a variety of DC machines available, including the Rotescograph and Magnographs I and II, in Canada, the NDT Technologies instrument, manufactured in the State of Connecticut, and others manufactured in Europe, South Africa, and Australia. All of these instruments are considered to be good, and more-or-less the same, as regards accuracy (NIOSH). It was noted that these people tend to be conservative and do a good job. Recently, comparative tests were made at both DMT, Bochum, and at the Pittsburgh Research Laboratory (Geller, personal communication). It was noted that, with one exception in each series of tests, all seriously underestimated the number of wire breaks in the tests at Bochum, and the loss of metallic area in the tests at Pittsburgh. It is crucial that wire rope inspectors must know the limitations of the instruments which they are using.

All manufacturers make various claims regarding the accuracies of their instruments and the proprietary algorithms that are built into them. It was noted, however, that the accuracies seem to be more-or-less the same (within ± 0.5% for LMA measurements) and there is little to separate these (NIOSH). These are much the preferred option to calipers, however, since the effects of corrosion are likely to be detected.

It was also said that a reasonable length of similarly affected rope, about 2 to 3 feet, is required for changes in the metallic area to be detected (NIOSH). In another observation, it was said that the LMA 250 instrument was found to present a simple straight-line chart of metal loss while the output of the Magnograph and Rotescograph instruments appeared to be more complex (Falconbridge).

One of the problems with all of the non-destructive tests is that these are very subjective and heavily reliant on the skills and the experience of the operator. In South Africa it is considered essential that all such wire rope inspectors must be extensively trained and have substantial and continuing hands-on experience [SABS 0293:1996, pp.25-30]. This is not the case in Canada and the possibilities exist that poorly-trained and inexperienced people can be entrusted with this crucial task.

The difficulties which surround these tests are numerous. In the first place, the NDT (Non Destructive Testing) equipment must be set up and the rope run through it at a rate at which the equipment operator is able to follow the trace and observe what the instrument is telling him or her about the rope. This is no easy task, as the South Africans point out. It takes years of experience to recognize the common causes of the changes being noted on the graph and to mark these accurately on the trace. The placement of the test heads is critical as also is the set-up on the testing instrument. In Germany (Gronau, 2000 05 29), it was noted that a speed of one metre per second is recommended for non-destructive testing.

It was also observed that it is acknowledged that the Loss of Metallic Area is NOT a measure of the Loss of Breaking Strength of the rope. Rather it was mentioned that one has to know how the rope is deteriorating and to use judgement (more is said of the point under the section on training). Further, while the instrument is considered to be good, it was noted that the output is not exactly what the regulations require.

One of the operational difficulties is that, while the tests are being performed, the hoisting conveyance is out-of-service to the mining operation. There can be no doubt that conflicts and pressures arise since the mine operator will want the rope to be tested as quickly as possible and at the highest winding speed, while the NDT inspector will generally want the exact reverse. In this instance the requirements of the inspector must prevail. This is not, and should not, be a cursory examination since a lot depends upon it.

Other operational difficulties concern the atmospheric conditions at the time when the test is being conducted, in particular the presence of water and cold. The test is not easy. It demands comfort and attentiveness at all times. Anything which detracts from this can compromise the validity of the interpretation.

Finally, throughout the visits great concern was expressed about the procedures through which non-destructive test instruments are calibrated prior to being used on actual on-site inspections. It was noted that there seems to be no consistency between operators, or even between the same operator on different days. All too often, it appears that the gain setting on the instrument is turned up until "it seems about right". It was noted that, beyond question, while there is a value to be obtained from such tests, there is a limit at which the output is a subjective decision of the operator rather than incontrovertible fact.

It has been noted as an important point that non-destructive testing should permit comparisons between repeated examinations of the same rope with the same machine over a long period. In this way, it would be possible to track the history of the same rope since its date of installation. Unfortunately, to date, instrument operators have not standardized on machine settings. Thus, there is little, if any, comparability between the results of the examinations of the same rope.

The focus on electromagnetic testing methods is to determine losses in cross-sectional area and breaks in the wires that constitute the cable. The former are shown as reductions in the general magnitude of the trace while the latter are shown as discontinuities or spikes.

In discussions at Rotesco (2000 09 07), it was observed that problems of interpretation arise when different machines and/or test heads and/or operators are used in susbsequent inspections. The differences in the ages and the models of the machines, the air gaps between the wire ropes and the test heads, the instrument settings, and the experiences of the operators all come into play as the causes of differences. This writer believes that there is a clear need for standardization.

In discussing electromagnetic testing, one point that must be made is that there are things which the instrument/operator can do, and, au contraire, there are things which can not be done. Generally, it is agreed that in the hands of a skilled operator, the tests can be very effective in locating discontinuities in the wires in the cable and losses of metallic area (LMA). This latter is thought to be directly related to loss of breaking strength (LBS) but there are some differences of opinion on this point. In the first place, there is no way that changes in properties, such as hardening, can be detected (OMOL).

An extremely important point is that, while electromagnetic instruments can detect indications of corrosion through both Loss of Metallic Area (LMA) and Local Fault (LF) measurements, the losses can cause serious underestimations of the loss of breaking strength of the rope. This is because the products of corrosion are also ferromagnetic and thus, the loss of metallic area as indicated by the instrument is an under-indication of the loss of strength (Kunn, p. 33).

Nonetheless, it has been mentioned that there is an impression that too many wire rope inspectors are looking at "the thing" (eg. the instrument) rather than at the rope. It has been commented that too much reliance is being placed on EM tests and too little in actually looking at the rope. A similar comment made in South Africa (discussions at Miningtek) was that too much emphasis was being placed on the non-destructive test and too little on the operator. A particularly poignant assessment was that it must be remembered that the person is "doing a rope assessment (and) not a machine assessment". It is not reassuring to see the results (traces) being sent elsewhere for someone who has not seen the rope. The South Africans, with all their vast experience are very firm on this point. It is critical that the person assessing the traces must have seen the rope while it was being tested. There is a need for much better training of wire rope inspectors and that is certain to happen in South Africa since the new Code of Practice (SABS 0293:1996) has now become law, and with this, the "grandfather clause" regarding rope inspections/inspectors will expire shortly (September, 2000).

Next, all non-destructive testing equipment must be calibrated from time-to-time. A twelve-month frequency is specified in SABS 0293 (Section 8.1.8) and it is noted that the rope used as a test piece (reference standard) during this procedure must be subjected to a tensile load which is10% of its estimated breaking strength. This is somewhat different than the procedures described in ASTM Standard E 1571-96 (see references), in which it is specified that the instrument should be calibrated before the first time that it is used, and periodically thereafter (Section 10.1.2). While both Wire Rope Reference Standards (Section 10.2) and Rod Reference Standards (Section 10.3) are described, and as no mention to loading on the tests pieces is made, it is assumed that these are unloaded during the procedure. Albert (communication) also noted that it is likely that the air gap between the rope and the test head will vary, as its length in the shaft changes during winding and unwinding, and as it stretches and relaxes.

Inasmuch as the ASTM Standard is the procedure followed in North America, and the SABS procedure will be required in Québec as a consequence of its adoption of the SABS Codes, there has been some concern as to whether or not the issue of loading the reference standard is important.

During the visit to South Africa this point was raised. Those responding to the question (discussions at CSIR, 2000 04 11; Mostert 2000 04 13-14) were unanimous in their opinions that the reference standard should be loaded for the following reasons; first, that loading the sample of rope "sets it up" to a condition most resembling that in-service; and, second, that this is an important issue in respect of South African instruments since the air gap between the tests heads and the wire rope is much less than is the case in North American practice. Thus, because of the small air gap, changes in rope diameter can have an important bearing on the accuracy of the result (with large air gaps a slight change in rope diameter would be of no consequence).

The procedure used in South Africa is such that a sample of the rope to be examined, 15 to 20 metres long, is placed under tension in a small test bed while the electromagnetic instrument is being calibrated. It was recommended that such a test frame should be constructed and available for use in Canada, if needed.

Finally, it has been emphasized that while electromagnetic methods of non-destructive testing work well with traditional six-stranded rope these do not work at all well with non-spin constructions. One of the problems is that eddy currents are generated at the magnetic sensor heads as the rope passes through these. These currents then tend to oppose the penetration of the magnetic field into the rope. In non-spin ropes, however, deterioration takes place towards the centre of the rope where damage can not be seen. To this should be contrasted the mode of deterioration in multi-strand ropes, which deteriorate from the outside, with broken wires visible. In locked coil ropes, it has been emphasized to the writer that the outer layers also hold the broken wires in place and are thus an effective screen preventing a view of the damage within (HSL, 2000 05 24). It has been stated repeatedly to this writer that non-destructive electromagnetic methods, while of much use for conventional stranded ropes, are of highly questionable value for non-spin constructions. It was noted that, while damage to the lay lengths does not occur in the latter, even a minimal amount of rotation upsets the balance between the outer and inner wires.

All of these reasons were given by several persons to explain why it is that the South Africans have more-or-less settled on using multi-stranded wire ropes of triangular strands for future deep mining operations. The fact is, that with their fibre cores, such ropes can be inspected with confidence using electromagnetic non-destructive testing methods. In simple terms, the reason that locked coil ropes are not to be used on hoists at great depth is that there are strong feelings that such ropes can not be adequately examined using present electromagnetic non-destructive testing methods. In other words "if you can't test it, don't use it".

Next, in Britain, Beck states that while a loss of 16% by wear or corrosion is permitted it is likely that the rope will be rejected for other reasons before this occurs (reference, p. 1.5).

In Germany, it was noted that initial electromagnetic tests must be performed within six weeks of the installation of a wire rope. Thereafter, however, subsequent tests must be performed at intervals which are established at each inspection by the "approved experts" (the practice being to have more than a single person present) (BVOS).

In Poland, the regulations state that hoist ropes and balance ropes (whether round or flat) should be subjected to standard magnetic tests within one month of installation (2.2.2.10., p.171), and thereafter at intervals of six months for hoisting ropes and one year for balance ropes (2.2.2.11., p. 171). It is noted that the records are to be added to the file on the rope.

Additionally, inspections are also to be performed after stoppages of operations have exceeded one month (2.2.2.12., p. 171), after emergencies resulting the clamping of skips, or overrunning the extreme levels of hoisting (i.e., over-winding), or emergency braking (2.2.2.13., p. 171). Further, after one year of operation hoist ropes must be subjected to testing using all available methods (2.2.2.15., p. 171). This period is extended to 1.5 years in the case of both round and flattened balance ropes.

In Hungary (Geller et al., B-21), the mining code requires that non-destructive testing must be performed with an "approved" instrument, by an expert who has successfully completed an "approved" lecture course. Further, it is required that, in addition to other requirements, the instrument must be able to reliably record a sudden 1% change in the rope's cross-sectional area.

Shaft ropes must be tested in situ, along the entire length, within 10 days of installation. Subsequently, non-destructive testing must be performed at regular intervals specified by the code. These intervals are functions of the shaft's loading cycle and the age of the rope. For hoisting ropes, the frequencies vary from a maximum of six months to a minimum of one month. For balance ropes, the frequencies are from a maximum of six months to a minimum of two months.

In Poland, it was noted (2000 06 01), that hoist ropes are to be replaced when a loss of metallic area of 20% has been detected over a length of rope that is equal to forty times the diameter of the rope. In the case of balance ropes the value is 30% for the same length. Both of these were believed to be too high, and reductions of 5%, to 15%, and 25%, respectively, were suggested as possible changes. Additionally, a value of 10% LMA is used for cableways due to the nature of the probable damage and the potential concentration of loss of metallic area in the areas rubbing against the guides and ground.

In Hungary, the code specifies that no rope shall be used as a hoist rope when the factor of safety, as determined by regular non-destructive testing, has decreased to 85% of the original value (Geller et al., p. B-21).

In the "Guidelines for Safe Mining" of the Province of New South Wales, Australia, it is stated that "the loss of metallic area for ropes used to raise or lower conveyances used for transporting personnel should never exceed 10%. In the case of guide ropes, however, losses in excess of 10% may be permitted if recommended by a competent person and if consideration has been given to: the areas of individual wires, the potential for broken wires to catch at the guide

contact point of the conveyance and counterweight, and, the other discard criteria of the Guidelines (p. 56).

As a general comment to this section it is to be noted that non-destructive tests are performed in every mining jurisdiction that was visited during this study. There was nobody who believed that these tests should not be performed. There is simply no substitute method through which an evaluation of the internal condition of a wire rope can be assessed. The methods, as imperfect as these are, are simply the best that we have available to us at present.

At the same time, all of those interviewed were the first to admit that technical advances are needed. While there was much discussion on the relative merits and demerits of the various instruments available internationally, there was no single instrument believed to be "perfect".

Another point of agreement was that there are wide variations between the inspection practices in the several countries visited during this study. The impression of the writer is that both South Africa and the European countries are further advanced than is the case in North America in the training and certification of wire rope inspectors, in the qualifying of instruments, in inspection procedures, and in records managment.

8) Loss of Diameter:

In the United States of America, the Regulations (57.19022) state that "after initial rope stretch but before visible wear occurs, the rope diameter of newly installed wire ropes shall be measured at least once in every third interval of active length and the measurements averaged to establish a baseline for subsequent measurements...". It is to be noted that the three measurements are irrespective of the actual length of the rope. In Regulation 57.19023 the frequency of both visual and non-destructive testing is specified, with the former being at least every 14 days and the latter at least every six months. Finally, Regulation (57.19024 (g)) states that a wire rope shall be removed from service when the diameter reduction due to wear exceeds 6% of the baseline diameter measurement. These diameter measurements may be made with calipers. It was noted that the precision of all such instruments should be verified.

In the new South African Code of Practice (SABS 0293:1996), distinctions are made between abrasive wear only with no clear signs of plastic deformation (5.7.1) and wear and plastic deformation (5.7.2). In each, further distinctions are made between round and triangular strand rope and multi-strand non-spin rope.

In situations of abrasive wear only on six-strand round or triangular-strand rope, it is stated that "where the wear is uniform around the rope circumference, the loss in rope diameter shall not exceed 7% of the nominal diameter of the rope "(5.7.1 (a)). Going further, in order to reflect the severity of damage from uneven wear: "where the wear is mainly on one side of the rope, the loss in rope diameter shall not exceed 5% of the nominal diameter of the rope" (5.7.1 (c)). For multi-strand non-spin ropes the corresponding losses resulting in discard for uniform and non-uniform wear are 5% and 4%, respectively (5.7.1 (b)(d)).

In situations where both wear and plastic deformation are observed, six-strand round or triangular-strand rope should be discarded when the loss of nominal diameter resulting from uniform wear exceeds 9% (5.7.2 (a)), and when the loss is mainly on one side of the rope and exceeds 7% (5.7.2 (c)). The corresponding values permitted for multi-strand non-spin ropes are 6% and 5%, respectively (5.7.2 (b)(d)).

In the Australian Guidelines, developed in New South Wales, it is specified that the rope (any rope) should be discarded if its diameter has been reduced by more than 6% due to wear, or for reduction of the diameter of the core, or for deterioration of the core, or for corrosion (p. 56).

In Poland, the regulations require that ropes should be inspected with a view towards determining the loss of cross-sectional area. Two methods are accepted. In the first of these, a slide caliper is used to determine the wear in those places along the rope where the greatest wear is detected (2.2.3. - 2.2.3.1, p. 171). The loss of metallic area is then determined from a table. In the second method, the caliper readings may be used to determine the loss of area through an equation (2.2.3.3., pp. 171-172).

9) Loss of Circumference:

In most of the jurisdictions visited by the writer it is common practice to clean sections of the rope periodically, to inspect these portions for wear, corrosion, and broken wires, and to measure the circumference with a tape, or calipers, specially prepared for the purpose. From such measurements one can become aware of loss of circumference through wear. This is a very basic measurement and should be included in any Code of Practice.

10) Loss of Mass:

Loss of mass is indicated by non-destructive electromagnetic instruments. While the term "loss of mass" has been used separately as a retirement criterion the intent is probably to think of it in terms of Loss of Metallic Area (Number 7, above). Nonetheless, the term has been used and is included in this list for completeness.

11) Broken Wires per Lay Length:

All of the regulations specify that a rope shall be rejected when over 5% of the wires (excluding filler wires) in a lay length are found to be broken. Structurally, it is to be stressed that within 1 lay length the wires have not been twisted sufficiently around each other for a sharing of the load to take place. Thus, at the very least, 5% of the wires in a broken state indicates that the rope has lost at least 5% of its breaking strength.

Both the Ontario and Québec Regulations [R.R.O. 1990, Regulation 854, Section 228 (19) f] [Québec @-2.1, r. 19.1, art. 291, 2] state that a rope shall be rejected when more than 5% of the wires in a "lay length", excluding filler wires, are broken (the lay length, it will be recalled, is the length of one complete spiral of the strands in the wire rope).

It is to be noted, however, that the regulations refer only to the total number of the wires that are broken in a given length and not to the distribution. It has been emphasized that this is just as important an indication as is the total number in a rope, since an irregular distribution can result in a strand failing. At INCO it was noted that if it is found that there is a concentration of broken wires in one strand the rope is changed immediately after the conclusion of that shift.

In the new draft CSA G4 removal criteria it is stated that one must consider not only the number of broken wires but also the types of breaks and the possibilities of the strands coming apart. Further, it is recommended that the wires next to the breaks must also be examined. It is suggested that if the wires are found to be located within one strand the rope should be replaced within eight hours and that both load and speed might have to be reduced within this period. Additionally, if the broken wires are found to be concentrated within two strands, the rope should be replaced within seven days, with the aforementioned conditions applying. INCO stated that it follows these recommendations.

In the United States of America (57.19024) it is stated that a rope shall be retired from service when: (a) the number of broken wires within a rope lay length, excluding filler wires, exceeds either- (1) 5% of the total number of wires, or, (2) 15% of the total number of wires within any strand. Further, ropes shall be removed, if (b) on a regular lay rope (if there is) more than one broken wire in the valley between strands in one rope lay length, and (c) a loss of more than one-third of the original diameter of the outer wires.

In South Africa the new SABS Code of Practice recommends (5.5.1) that a distinction be made according to the construction of the rope. For one lay length of six-strand round or triangular strand constructions, it is stated that if more than half of the visible broken wires are in two adjacent strands, the total loss in normal wire area owing to these wires shall not exceed 4%. Further, for one lay length of the same rope constructions, it is stated that if half of the visible broken wires are distributed in more than two adjacent strands, the total loss in nominal wire area owing to the broken wires shall not exceed 7% of the nominal rope steel area.

For all other constructions the number of visible broken wires in a single strand of one lay length shall not exceed 40% of the total number of outer wires in the strand. It was noted that detailed criteria for the various constructions of multi-strand non-spin ropes are being developed by the CSIR-Cottesloe (The Council for Scientific and Industrial Research). In discussions at CSIR's Miningtek division, on 2000 04 11, it was noted that several different types of wire failures are noted for non-spin ropes. If such ropes are used on drum winders, for example, it has been observed that it is the outer wires that break. On friction winders, however, the opposite is true, with the failures being in the inner wires of the construction. It was understood that the criteria for various rope constructions have been developed. These have not been seen by this writer, however.

One comment made was that, according to the South African retirement criteria, as few as two broken outer wires in a non-spin rope can "cost the rope". To address this, and with view towards assessing whether or not non-spin hoisting ropes can be recycled, consideration is being given to the possibilities of removing an entire strand from a damaged rope and replacing it with a new strand.

In the same document (SABS 0293:1996) it is recommended that the number of broken outer wires in five actual lay lengths shall not exceed twice the limits mentioned above (5.5.2). Further, there shall be no broken wires immediately adjacent to, or within two lay lengths of, the rope side of a termination (splice, cappel, or socket) and no broken wires shall be within three lay lengths from the contact point of compensating sheaves (5.5.3).

One of the difficulties of using broken wires as a criterion, however, is that it is tacitly assumed that the damage is uniform for the entire length of the rope. Mike Van Zyl, of South Africa, pointed out, however (2000 04 18) that the results would be completely different for 10 metre and 100 metre samples. He noted that there is an urgent need to re-think the broken wire criteria and pointed out that, if one can not establish a relationship between loss of breaking strength and loss of metallic area for six steel bars which had been somewhat reduced in section, how could one do the same for wire rope, which is much more complex in construction?

During the visit to Poland it was noted that there is no criterion in place through which wire ropes are rejected on the basis of broken wires (Hansel/Olesky, 2000 06 01).

In the "Guidelines for Safe Mining" developed for the Australian province of New South Wales, it is specified that ropes should be discarded if the number of broken wires within one lay length cause a loss of rope metallic area greater than 5%, for non-uniformly distributed broken wires, or 8% for uniformly distributed broken wires (p. 55).

Further, if the number of broken wires within one lay length of any strand exceeds either 15% of the total number of wires, or 40% of the total number of outer wires in that strand, excluding filler wires, the rope shall be discarded (p. 55).

In addition, further criteria are that ropes are to be discarded if the number of broken wires identified in five adjacent rope lay lengths is double that permitted for one rope lay length, and, if there is more than one visible broken wire within a rope lay due to in-service effects between strand-to-strand contact points in a rope valley (p. 55).

12) Broken Wires per "Critical Length":

In Germany, it was noted (Gronau, 2000 05 29) that the length of the sample used is not the lay length of the rope but, rather, a length which is equal to 15 times the diameter.

In his paper (Beck, p. 1.5) mentions that the experience from Germany indicated that there was a ratio of 1 : 2 between the loss in strength of the rope due to broken wires and the loss in strength due to wear and corrosion. He also notes, however, that the length of the German samples were 50 times the diameter of the rope. This is a point which requires clarification.

In Hungary (Geller et al., p. B-21), the code specifies that no rope shall be used as a hoist rope when the number of breaks in individual wires, along a 10 metre continuous length of rope, exceeds 10% of the overall number of load-carrying wires. In the case of balance ropes the similar rejection criterion is 15%.

13) Broken Wires per 150 to 200 feet of Rope:

In the conversations with the writer in South Africa it was noted that, at the Homestake mine, in Lead, South Dakota, the company has developed its own criterion for discarding wire ropes. This action was reported as being taken whenever it is found that there are 150 to 200 broken wires over a 150 to 200 foot length of rope. At Homestake, the hoist being inspected is a 6-rope friction hoist. The practice has been to replace one rope at a time, whenever required according to the above criterion (NIOSH).

14) The Lay Length of the Rope:

Extensions in the lay length of a rope can indicate either that it has been stretched excessively or that the rope is unwinding.

As far as the writer could determine, this criterion is not included in either the Ontario or Québec Regulations or in the United States of America. These are, however, covered in the new South African Code of Practice (SABS 0293:1996). In these, provisions are made for local variations, slack strands, and general variations. As with the other South African discard criteria distinctions are made between the principal types of rope constructions.

With reference to local variations in six-strand ropes, the SABS Code recommends discard when "any local lay length increase or decrease exceeds 12% of the average of the lay lengths on the unaffected sections on both sides of the anomaly" (5.10.1 (a)). For multi-strand non-spin ropes the corresponding criterion is 5% (5.10.1 (b)).

For multi-strand non-spin ropes "any slack strand(s) and also any relative strand movement of more than one strand diameter, in the case of round strands, or strand altitude in the case of shaped strands, shall be reason for discard" (5.10.2).

As regards general variations it is suggested that six-strand constructions of rope should be discarded if any lay length decrease exceeds 30% of the normal lay length of the rope, and if any lay length increase exceeds 100% of the nominal lay length of the rope (5.10.3 (a)). Both criteria are set at 12% (i.e., decreases and increases) for multi-strand non-spin ropes (5.10.3 (b)).

15) Wear of Crown Wires:

In the discussions at INCO (2000 03 28) it was noted that wear of the crown wires has never been a reason by itself to reject a wire rope. It is usually associated with other(s) of the defects noted. Nonetheless, wear of the crown wires may indicate a loss of metallic area and consequent loss of strength. It is to be noted, however, that plastic deformation of the crown wires can appear to be similar to wear.

While this criterion is not included in the present Ontario Regulations, it is included in the new draft CSA G4 removal criteria. In this document, it is recommended that the wires be cleaned carefully so as to determine if the loss of metal on the crown is due to wear or peening. In addition to making measurements of the diameter of the rope, all of the parts of the hoisting

system with which the rope comes into contact are to be inspected to determine if repairs are needed in order to reduce the wear of crown wires. These include the hoist drum, the grooves on it, the rope risers, the crossovers, and the grooves on the head sheaves and any idler sheaves. If there is 1/3 loss in the crown wires due to wear it is recommended that the rope should be replaced within seven days. INCO (2000 02 28) stated that it operates in accordance with these recommendations.

In the British regulations, according to Beck (reference, p. 1.6), a loss of one-third, or 33%, of the original diameter of the outer wires is a criterion for the rejection of a rope.

16) Corrosion:

In the United States of America, the Regulations (57.19024 (d)) state that a rope shall be retired from service if there is deterioration from corrosion. As has been mentioned in a preceding section {(4), Reduced Wire Torsion Turns}, similar provision as also included in the Ontario Regulations [R.R.O. 1990, Regulation 854, Section 228, (19) a].

The new South African Code of Practice is more complicated and states: "when the calculated loss of strength owing to corrosion is based on magnetic measurement of rope steel area, the indicated loss of steel area shall be multiplied by the conversion factor for the specific rope construction and instrument combination used. The loss of strength so calculated shall not exceed 10% of the new rope breaking strength" (5.6.1). Further "pronounced pitting or roughening of outer wires that is caused by more than a slight corrosion or worse (as illustrated in figures A.5 to A.8, in said S.A. Code's Annex A) shall be reason for discard" (5.6.2).

A comment was made (HSL, 2000 05 24) that a point to look for is that the upper wires on a rope may appear to "pop up" as the result of corrosion.

As noted in a previous section (Loss of Metallic Area), Beck mentioned that a loss of 16% due to wear or corrosion are permitted in the British regulations but that it is likely that a rope would be rejected for other reasons before this point arrived (references, p. 1.5).

Next, in the Guidelines for New South Wales, in Australia, it is specified that ropes should be discarded if the diameter of the rope has been reduced by more than 6% due to wear, core diameter reduction, core deterioration, or corrosion (p. 56).

C. Visual, Observed and Monitored

17) Age:

As mentioned previously, considerable heat is generated as wires are pulled through dies to size them. It is thought that this results in a change to the structure and properties of the metal which results in the wires becoming embrittled with time. The process has been referred to as "strain aging". Because there is some concern that wire ropes, and particularly high-tensile stranded cables, can deteriorate with time, some jurisdictions have regulations in place to ensure that a rope which has been in storage for a long period shall be tested before it is placed in service. In

Manitoba, the writer understands that a destructive test is required once the rope has been left on the reel on which it is supplied for more than two years. In Québec, the regulations stipulate that a non-destructive test must be performed once a rope has been in storage for more than five years [Québec, S-2.1, r. 19-1, art. 304.1].

In South Africa it was noted that ropes can be in storage for a very long period - up to several years. In such cases, testing is required before the rope can be placed in service.

The United Kingdom is the only jurisdiction that the writer is aware of in which the regulations are framed in terms of approving a wire rope for use during a certain period - 3.5 years in the case of a drum winder and 2 years in the case of a friction winder. Thereafter, the inspector can permit extensions as long as it is deemed that the rope is safe. The inspector may also write an exemption for a period if new practices are being studied or if conditions warrant. An example would be increasing the period between destructive tests from six months to a year if it is found that there has been very little loss in strength during the shorter period.

Concurrently, requirements and conditions, such as for inspections and testing, may also be imposed if conditions warrant these.

18) Ton-miles:

During the conversation with Professor Chaplin (2000 05 25), it was noted that the American Petroleum Institute (API) uses a criterion for the rejection of the wire ropes used to haul drill stems which is based on the tons hauled and the total cycles. Thus, after a certain number of "ton-miles", the ropes are replaced.

19) Total Tonnage:

Likewise it was reported that certain major mine operators had adopted the practice of rejecting wire ropes for further service once a particular total tonnage had been hoisted (in the instance quoted, 1 million tons). To date, the writer has obtained no documentary evidence of this. Thus, this criterion, until proven otherwise, is anecdotal.

20) Duty Cycles:

Thus far, the writer has not found any reference to ropes being rejected after a given number of duty cycles. It was said, however (Gronau, 2000 05 29), that all reports of calculated aggregate strength in Germany also contain mention of the total work that has been done by the rope at the time that the sample was obtained.

21) Heat:

Heat, and particularly fire can cause severe damage to a wire rope and is sufficient cause to reject the rope immediately. It can be assumed that, by being exposed to heat, the physical properties of the rope have been severely affected. Other causes of heat damage can include the frictional heat resulting from improperly aligned or jammed sheaves.

In the United States of America, the Regulations (57.19024 (f)) state that a wire rope shall be retired from service when there has been heat damage from any source.

In South Africa, it is stated that "pitting and discolouration or any other signs of electric arcing or of other heat effects or of suspected heat effects shall be reason for discard" (5.11).

In the Guidelines developed in the Australian province of New South Wales, it is noted that heat damage includes not only general overheating but also localised overheating and damage due to lightning strikes (p. 55). Given the frequency and severity of summer thunderstorms in Canada, it might be to the point to include this in Canadian Guidelines, when developed.

22) Damage to the Structure of the Rope (including the core):

Some regulations make provision for the rejection of a wire hoisting rope whenever it has been determined that there has been severe damage to the structure of the rope. Such damage includes kinks, nicks and cuts from falling objects, and strands which protrude noticeably.

In the United States of America, the Regulations (57.19024 (e)) state that a wire rope shall be removed from service when there has been any distortion of the rope structure.

Once again, the SABS Code of Practice (SABS 0293:1996) is more specific and refers to discard criteria for waviness, bends, and kinks.

With reference to the former, a further distinction is made between six-stranded ropes of round or triangular strands and multi-strand non-spin constructions. For six-strand ropes it is stated that "over a span of two wave crowns or over a distance of four actual rope lay lengths, whichever is the smallest, the gap between a straightedge (sic. ruler)(placed longitudinally against the rope) and the rope surface shall not exceed 25% of the nominal diameter of the rope" (5.8.1 (a)). For multi-strand non-spin rope the corresponding discard criterion is given as 15% (5.8.1 (b)).

Regarding bends, it is stated that a rope should be discarded when, over a distance of two actual rope lay lengths, the gap between a straightedge (sic. ruler) (placed longitudinally against the rope) and the rope surface exceeds 6% of the nominal diameter of the rope (5.8.2).

Next, it is stated that "a section of rope shall be discarded if there is any kink" (5.8.3).

Finally, in a separate section, it is required that a rope shall be discarded when there is "any indication of a fibre core failure, independent wire rope core failure or main wire core failure" (5.9).

23) Short Ropes:

Wire hoisting ropes should be discarded when these have become too short to permit sections to be cut-off at the attachment of the rope to the conveyance.

In the South African Code of Practice (SABS 0293:1996) it is stated that; "a rope shall be discarded when insufficient spare rope (as per regulation 16.6.5 of the Minerals Act, 1991) remains for cutting of the front end or of the back end in order to: (a) provide legally required front end test samples, (b) pull in the back end for sound rope maintenance requirement, or, (c) remove defective sections of the rope in the vicinity of the rope ends" (5.13).

24) Overloading:

In the "Guidelines for Safe Mining" developed for the Australian province of New South Wales, it is noted that ropes should be discarded if overload damage has occurred to the rope, unless a competent person has recommended, in writing, that the rope is safe for continued use (p. 56).

25) Combined Effects:

During the discussions that were held concerning the aims and objectives of this study it was mentioned that wire ropes are seldom discarded for one reason alone. Most often, there are several reasons, which, when considered together, become adequate justification for discarding the rope.

This is now written into the new South African Code of Practice (SABS 0293:1996), in which the wording is: "Where different deterioration modes act simultaneously at any point in the rope, their combined influence on the rope strength shall be estimated. The individual levels of deterioration expressed as fractions of the allowable maxima shall be added together. This is particularly important where broken wires occur in association with diameter reductions caused by plastic deformation and wear" (5.13).

In Hungary (Geller et all, p. B-21), ropes must be rejected whenever the inspector forbids further use and gives instructions for its replacement. During the writer's visits, it was understood that similar regulations apply in Germany.

In the Guidelines written for the Australian province of New South Wales, it is specified that ropes should be discarded if "any combined effect of the above (i.e.,loss of strength or excessive stretch) is such that there would be little doubt that the rope does not retain at least 90% of its original required breaking force" (p. 57).

26) Rate of Deterioration:

In the foregoing parts of this section it has been mentioned that "advisories" or warnings are often issued to a mine operator when it is noticed that the wire rope is losing strength for a variety of reasons.

This, too, is included in the South African Code of Practice (SABS 0293:1996) as: "A rope, or a section of rope, shall be discarded when the rate of deterioration is such that the limits specified in [Sections 5.5 (visible broken wires), 5.6 (corrosion), 5.7 (change in rope diameter), and 5.14 (combined effects)] could be reached before the next examination. To avoid this, the interval between examinations may be decreased" (5.15).

27) Damage Indices:

In Canada, and elsewhere, research is in progress to integrate as much information as possible from non-destructive testing results into a single value, or index (Hamelin et al., references). The objective is to bring these data together, electronically, into a single signal through which the overall quality of a rope can be monitored continuously. Thus, the development of a Rope Damage Index, or RDI , would be an important step towards continuous monitoring of in-service mine hoisting ropes. At present, an in-situ field evaluation of both a monitoring system and the Rope Damage Index is being conducted at the Louvicourt mine, near Val d'Or, Québec.

General Comments

The criteria which are listed and described above have all been developed with a view towards assessing whether or not the in-situ condition of a mine hoisting rope is satisfactory, and whether or not the rope should be retired from further service. Some are very empirical and are based on operational experiences, while others have a more scientific and engineering footing.

Nonetheless, all involve some uncertainties and all require that judgement be exercised in their application. The numbers, where these are used, have been chosen with an important objective in mind – namely, how to prevent the possibilities of an unanticipated failure of a mine hoisting rope.

For a variety of reasons, at present it is neither preferable nor possible to discard any of the criteria that are written into the regulations in the mining jurisdictions that were visited by the writer. In every case, compelling reasons were given as to why these should be retained.

As regards destructive tests, for example, it was stated repeatedly that these are the only means of arriving at hard numbers that reflect the strength of a mine hoisting rope. Whether or not the samples have been obtained from the best places is a separate issue, but, since wire ropes can not be cut and spliced with any assurance of retaining integrity, the choices of where samples can be obtained are limited.

Finally, visual and subjective methods are also an effective first line of defence in the inspection of a wire rope. Repeatedly, however, it was said that these are often neglected by operators and that not nearly enough attention is paid to the necessity of making thorough, daily, pre-operating inspections.

16. The Training of Wire Rope Inspectors

Heretofore there has been no formal program through which wire rope inspectors have been trained, either in any of the geopolitical subdivisions in North America or in North America as a whole. It is perhaps because of this, that one of the comments that was frequently made during the discussions concerning this study is that there appears to be a very broad spectrum of the experiences and training that wire rope inspectors in North America bring to their jobs. Many of those in non-destructive evaluations, it would appear, lack substantial field experience and skill in interpreting the readings that have been obtained on site. It has been noted that turnover is high because of the demands for travel and the oft-unpleasant nature of wire rope inspections in the field. Nothing seems to happen the same way in the field as it did in the laboratory, one has to know how to set the test heads in order to obtain good results, and its dirty. All of the procedures take time to follow and, because of the demands for production from operators, there can be pressures to "get on with it" while the work is in progress. Albert (communication) has noted that most field inspectors do not last for more than two to three years. Some of the difficulties in making on-site inspections were also discussed during the writer's visit to Rotesco (2000 09 07).

In addition, there are contractor issues to resolve on the site (NIOSH). Contractors, as all others on a mine site, must follow the established safety rules. Increasingly, introductory orientation and training are being required. This is mandatory in both Ontario and Québec.

At present, there are no standards regarding the basic qualifications, field experience, or training for wire rope inspectors in North America. Without wishing to appear to be overly critical, it seems that anyone can purchase one of the instruments available, obtain basic training which is provided by the vendor, and immediately set off to perform wire rope inspections.

To this should be contrasted the course which is followed in South Africa through which inspectors pass through various levels according to their background, experience, level of training, ability to pass prescribed examinations, and exercise demonstrated judgmental skills.

In Germany (Gronau, 2000 05 29), it was emphasized that Rope Inspectors are only qualified as such after five years of experience following their graduation from university. During this period of further training the candidates are employed full-time in using various methods of non-destructive inspections, testing, and analysis. Formerly, at the peak of the German mining industry, it was possible for persons to be fully engaged as the inspectors of mine wire ropes. With the decline of the industry, however, the trend has been towards generic NDT inspectors who probably devote about 25% of their time to mining applications. Nonetheless, the level of experience that is required in order to qualify is very high.

In Poland, it was noted (Tytko, 2000 06 01) that wire rope inspectors are qualified after an extensive period of training. As a basic requirement, all must first possess a university Diploma in engineering (Dipl. Eng.). This is then followed by five years of experience plus two academic terms at the University of Mining and Metallurgy, in Kraków. This further training is in all aspects of wire rope technology and inspection theory and practices. It was also indicated that one-week courses are offered to foreigners wishing to receive instruction in the subject.

During the discussions in Canada, it has been widely emphasized that there is an urgent need for standards of training to be developed. In the knowledge that Canadian mines will be developed to greater depths and that the safety of wire hoisting ropes will become critical to future operations, it is certain that a higher level of skills, understanding, and judgement will be required.

Some have expressed the view that it is the responsibility of those firms engaged in the craft to invest in the development of their skills - either at home or abroad - while others have suggested that the potential market is so small that there should be some partnering in arranging skills enhancement. Potential partners have been identified as being the industry or various levels of government. The former will require the skills in support of their operations, while the latter may have a role to play in bringing new skills into Canada and in bridging the gap between the present, where there may be relatively few customers for the levels of skills that could be demanded through the implementation of the South African Standards, to the future when there will probably be several deep mines, and thus an adequate client base to support a few highly trained people.

Regardless of the means of financing such skills-upgrading some of the options are:

(1) to encourage manufacturers to provide much more thorough and intensive training
(2) to urge the Canada General Standards Board, the CGSB, to provide their Certified NDT Inspector, Level II program of study (as amended as necessary) to wire rope inspectors
(3) to suggest that CANMET do the same, on the basis of their NDT testing experiences
(4) to adopt the South African curriculum and to make arrangements for Canadian wire rope inspectors to participate, either through direct on-site studies or through distance learning
(5) to develop a course of study, experience, and certification in Canada which is acceptable to the Mines Inspectorates.

Whatever the costs and inconveniences it must be borne in mind that there is a general agreement that the skills of wire rope inspectors must be enhanced. Any margins of safety that we have enjoyed in the past will be eroded as lower safety factors are permitted and as high-tensile strength wires are used increasingly.

Acceptance of the South African Code of Practice in Canada carries with it the obligation that all of its aspects must be accepted without reservation. Mine operators can not have selected parts of the package. It is a critical issue that we recognize that the package was developed as an integrated whole based on many years of experience. Thus, in the interests of mine safety "half a loaf" should not be an option. It should either be "the whole loaf" or none at all.

Acceptance of the South African Codes of Practice (SABS 0293:1996 and SABS 0294), by Québec, also brings with it the precedent that, for one of the first times, foreign codes of practice have been accepted as references in Canadian regulations. Presumably, similar situations could

arise in other Canadian jurisdictions, with the result that our regulations could become incredibly complex and difficult to harmonize.

Regardless of the costs and inconveniences it must be emphasized that Canadians must take urgent steps as the result of the adoption of the South African Code of Practice in Québec, and perhaps in Ontario and elsewhere. We need to develop not only a plan for the long term but also one for the short term which will bridge that period when we are lacking persons with the skills to be recognized as wire rope inspectors at the accepted levels of competencies that prevail in South Africa.

There is a need for a "home-grown" national code, that is written with the conditions that are distinctly Canadian in mind (climate), and which will reflect our ambitions for our future. It is very possible that the development of such a code, and standards, could become important precedents and incentives towards the process of harmonization which is needed so urgently.

In the meantime, it is to be noted that the SABS program of study involves both aspects of practical experience and self-study. The former includes: (1) methods of assessment; (2) the types of equipment, calibration, and use; (3) performing the calculations to determine if a rope should be rejected; (4) assessment procedures; and, (5) interpretations of results. The latter includes: (1) knowledge of wire ropes and applications in which these are used; (2) the legalities; (3) all aspects of wire rope technology; (4) the causes and types of wire rope deterioration; (5) assessment techniques, including visual examinations, and destructive and non-destructive testing; and, (6) rope assessment procedures and discard procedures.

Persons selected for training as an Assistant Winding Rope Inspector must have had six months of experience in a hoisting plant as well as technical training (probably equivalent to the 2-year Technician or 3-year Technologist levels in Canadian Community Colleges). After a full year of receiving instruction and having assisted with rope testing, the candidate, on being recommended, is permitted to write the SAQCC (South African Qualification and Certifications Committee) Level I examinations.

After being designated as an Assistant Winding Rope Inspector (SAQCC Level 1) the candidate then undertakes a further program of study lasting 18 months. During this period both increasing levels of skills and responsibilities are required. On completion of this, and having been recommended, the person may take the SAQCC Level 2 examination. Successful completion of all aspects of the program leads to the designation as a Winding Rope Inspector, which brings with it the ability to perform all field work independently. At this level, the Inspector assists in the training of others progressing through the system.

It is the writer's understanding from discussions with both the CSST and CANMET staff at Val d'Or that, for the foreseeable future, inspectors from South Africa will inspect the plant at Agnico Eagle's Laronde mine on a semi-annual basis. As is the current practice for mines across Canada, any destructive testing that is required will be requested of OMOL's facilities in Sudbury.

Meanwhile, in the interests of developing the skills of Québeçois, the CSST is looking to either CANMET or another organization to develop a plan and curriculum for the training of inspectors to South African levels. Inasmuch as CANMET is presently involved in the inspection of hoisting plants in Québec (as the result of the transfer of this function several years ago from the Association Minière du Québec) it may be perceived as being in a conflict of interest if it does so until such time as its own personnel have been suitably trained and certified.

Commencing immediately, there will be an interim period of approximately two years when Canadians will have "to come up to speed". During this period it was understood that a first step towards a transition to a resident Canadian expertise will begin when Vincent Rodier, of Labcan, commences training towards SAQCC Level 1 in June, 2000. It was noted that, in view of his four years of non-destructive testing experience with wire ropes, the South Africans have recognized his experience as being equivalent to that required to commence the advanced in-house training towards the Level 1. After completion of a one-month period of training, he will probably write the examination. On successful completion, a certificate attesting to Level 1 status will be issued.

Thereafter, the next step will consist of monthly tests being performed at Agnico-Eagle's Laronde mine with the results being sent electronically to Sarel Mostert, of AATS, for his overview. At approximately quarterly intervals the latter-mentioned will visit the mine to conduct direct on-site tests. If all proceeds according to plan, after about one year, Mr. Rodier will be permitted to undertake the final stages of preparation for the Level 2 SAQCC certificate. On receiving this he will be able to conduct evaluations independently, and Canada will be on it's way to a completely resident expertise.

It is to be noted that Labcan will undertake all of the expenses in the nature of the development of its expertise and competitive position in Canada.

It was mentioned that conversations are being held with the South Africans requesting that the practical experiences of Canadian wire rope inspectors be reviewed and that those having the practical experience required to take the SAQCC Level 1 examinations in South Africa be permitted to do so. At some stage soon it is hoped that the full program of study and certification can be offered in Canada. It has been noted that the cost of doing this by sending persons abroad for extended periods would be prohibitive (CANMET).

It was also noted, during discussions at CSIR-Miningtek, in South Africa (2000 04 11), that Training Manuals for the Wire Rope Inspectors courses leading to qualification are available for purchase at the South African Qualification and Certifications Committee (SAQCC).

17. Advantages and Disadvantages of the Criteria

During the discussions with those who have been interviewed during the course of this study much has emerged concerning the relevance and validity of the several criteria by which wire ropes are removed from service. It has been mentioned (NIOSH) that not all of the criteria correlate for a single rope and, further, that separate criteria are required for the several different rope constructions that are presently available. A recommendation to this effect is made later in this report.

In the meantime, it is meaningful to review the comments that have been made on the various criteria. Some have been criticized while others have been rejected outright. The object of the exercise is to focus on those criteria which have received the most, or unanimous support. These have been: visual inspections, loss of breaking strength, reductions in diameter, corrosion and the conditions of the wires.

Everyone interviewed said that there is absolutely no substitute for visual inspections, and that this is the single most essential part of wire rope and hoist inspections. Yet, this is one of the aspects that can be easily neglected. The cause can be lack of time, lack of diligence, or lack of interest.

In all instances, in making inspections it is essential that the rope be run at speeds which are slow enough to permit the inspector to monitor what is being indicated on the electromagnetic equipment (if this is being used) or what he or she sees. If broken wires are indicated, there must be an opportunity to stop the hoist and examine the rope at that point.

Likewise, everyone interviewed stated that the condition of the wires is by far and away the most meaningful of any of the criteria when it comes to judging the condition of a wire hoisting rope. Broken wires and excessive wear of the crown wires and surface corrosion almost always will cause a rope to be discarded long before losses in diameter are sufficiently great to justify the same result. It is the crown wires that will wear and break. In some of the regulations valley breaks are also mentioned. This is considered to be a valuable criterion, for, the experience is that such breaks are an expression of very bad fatigue in the rope. Further, if the broken wires are expressed as a percentage of the total wires, the construction of the rope becomes immaterial (NIOSH). Thus, this is one criterion that does not have to be written differently for each and every type of rope construction.

It was also noted that local faults indicating broken wires also correlate well with measurements of loss of metallic area. In a dissenting view, however, Mike Van Zyl, challenged the relationship between loss of breaking strength and loss of metallic area by noting that, if it is difficult to establish this for six bars which had been necked down, it would be very much more difficult to do it for the complex construction of a spun wire rope. He suggested that this criterion must be re-thought.

He noted that, even with a broken strand a rope can still retain 95% of its strength. He noted that one can use any criterion that one wants, but that, in the final analysis, one must be confident in the strength that remains in the wire rope!

Next, most persons stated that there is presently no substitute for the destructive tests to determine the loss of strength that may have taken place in a wire rope. It was mentioned again and again that this is the one "hard number" that is available and that there is no substitute for it. Nonetheless, the destructive test is not necessarily representative of the very worst section of the rope - which may be at the cappel, or elsewhere.

Most of the people interviewed were quick to point out that non-destructive tests, while providing useful information, have many deficiencies and are useful only as an indicator. Frequent reference was made to the fact that all of these instruments, without exception, are very poor when it comes to detecting corrosion in a wire rope (both wire and oxidized wire are ferromagnetic). To some, such as in South Africa where climatic and underground conditions are such that corrosion is rare, this may not be a major concern. To others, however, and to Canadians in particular, this could be a major issue. Geller, however, disagreed with these comments (personal communication) and noted that, while it may be difficult to detect corrosion on the Loss of Metallic Area (LMA) trace, one can detect it on the Local Fault (LF) trace. Thus, if both traces are available, the problem is less serious.

During the discussions, reference was also made to the use of criteria based on the age of the rope. "Age", in this instance could be shown as either year, or total tonnage hoisted, or ton-miles. The point was made, however, (Chaplin 2000 05 25) that criteria based on age can be very unsatisfactory since these can mitigate against bad practice. Rather, one should adjust what ones hauls based on what one sees.

When it comes to judging the validity of the various criteria, however, there can only be one pre-eminent question, and that is: "how many ropes have been rejected because of the application of it?" The response to this question will probably never be uniform and will vary from place to place. In the United States of America, because the great majority of its mines are exceptionally shallow it is unlikely that wire hoisting ropes will be rejected because of losses of breaking strength. Rather, this is likely because of physical damage to the rope. In Canada, a nation which is characterized by a great many sulphide deposits, it is probably fair to say that corrosion (from acid mine waters) is one of the principal reasons for discarding wire ropes. In the Republic of South Africa, however, the picture is completely different since most of the mines are exceptionally deep by North American standards and it is here that most ropes are tested to their limits in the sense of strength.

The question that must be addressed then, is which criterion or criteria is appropriate for each of these particular and different circumstances?

Because it seems likely that a wire hoisting rope is seldom rejected for one reason only, a second questions is: had the rope not been rejected for the reason stated, is it likely or certain that it would have been rejected for some other?

This leads into the concept that new criteria are required. In the first instance, as has been mentioned in both the United States of America and the Republic of South Africa, one must recognize that all constructions of ropes are different and that the mechanisms which damage these will also be different. McCain, at NIOSH, has been very eloquent in making this point,

and, as far as the writer can determine, the first movement in this direction has been through the new Code of Practice, SABS 1996:0293, which has been adopted in the Republic of South Africa. There is still a long way to go in this area, but at least the first steps have been made convincingly! It is to be noted that this development is compatible with what has happened in other industries in which wire ropes are used, particularly the aircraft industry (Chaplin, 2000 05 25).

Going beyond this, however, and in the knowledge that wire ropes seldom are rejected for one cause, but, rather, several, this writer is supportive of the concept of a "damage index" which could be used to express the total damage which has taken place through the full variety of causes. It is to be noted that how the factors will be determined and the relative weighting that should be assigned to each is judgmental, controversial, and subject to considerable future debate. Nonetheless, the concept is a good one, and discussion on it should advance the state-of-the-art in the evaluation of wire ropes.

In saying this, it should be added that any "Damage Index" will probably relate to a particular installation, a particular application, and a particular rope. If any of the parameters are changed, particularly the rope construction, the situation will change drastically (Chaplin, 2000 05 25). Thus, recognizing the different way in which the different constructions of rope deteriorate, it is probably reasonable to suggest that "damage indices" should be determined for each and every type of rope.

Finally, Chaplin (2000 05 25) made the point that, to date, many of the discard criteria are based on the strength which remains in the wire rope. Recognizing, however, that there are several means of degradation, we need to adjust our thinking to consider not only the strength remaining in the rope, but also the life.

18. A Look into the Future - the Views of Key Players

At present, there is no doubt that the Canadian mining industry will be driven to mine orebodies at greater depths. Fewer major deposits are being discovered near the surface, and those that have been have been delayed as the results of negotiations between the stakeholders. There are no shallow "elephant class" underground mines about to come into production in the country. Barring a major discovery, this is not likely to happen in the near future.

There are, however, several significant orebodies which are located beyond the depths at which underground mining is presently taking place in Canada. The impediments to mining these are both economic and technical. From the point of view of economics it will be incredibly costly to develop and operate deep underground mines. Technically, it will be necessary to either adapt present mining methods or to develop new approaches which will be suitable for extracting orebodies under conditions of great ambient rock stresses and temperatures. An important focus of the mining industry is on Deep Mining. Several organizations, notably INCO, Falconbridge, and CANMET, have devoted considerable resources to investigating the ways in which the frontiers can be advanced. It is a measure of how far mining has progressed within the past century to recollect that the first Deep Mining Act in Canada was enacted in Nova Scotia in 1905 to provide a means of compensating mine operators for the additional expenses engendered in sinking shafts beyond 500 feet.

"Deep", in many respects, is synonymous with "difficult". The frontiers of mining under increasingly adverse conditions have been pushed tremendously during the 20th Century. There is no reason to suspect that we will yield to the new limits now. For the present, we dare not. The futures of several of Canada's important mining communities, notably Sudbury, Timmins, Rouyn-Noranda, and Val d'Or, will be greatly influenced by our new-found abilities to exploit orebodies at greater and greater depths.

There will be a requirement to sink shafts to the absolute limits that are technically possible.

In this context, the wire hoisting rope is the lifeline of an underground mine with shaft access. It is the strength of the wire rope and the factors of safety which must be applied in the design of the hoisting plant that will limit the depths to which shafts can be sunk. At present, the trends in South Africa have been to the adoption of a new Code of Practice and also a Standard for the assessment of the conditions of mine hoisting ropes. In this writer's view the two are inseparable and must be taken together as a combined package. In the Code, for example, are explained the ways in which the South Africans have progressed towards factors of safety which are much less than we have accepted in Canada.

In doing this, a major part of the rationale rests on assurances that ropes can be operated within these new factors of safety through eliminating the stresses which result from dynamic loading. It has been mentioned previously that our factor of safety of 5.0 at the sheave implies that, at that point, 80% of the strength of the rope is available as "reserve strength". Delorme, however, estimated that the stress on the rope could be doubled through the dynamic effects of dumping ore from the loading pocket into the skip. That, in itself, would immediately reduce the factor of safety at the sheave to 2.5 and only 60% of the rope's strength would then be available as

"reserve strength". Emergency braking would add yet another stress to the rope and could effectively reduce the factor to as low as 1.6 (with only 40% of strength being available as "reserve"). The blunt fact is that there are probably many instances today when we are operating at factors well below those which are required. The positive side of this is that, as in South Africa there is probably some movement possible towards our acceptance of the South African Standard.

In doing so, however, we must, concurrently, and without exception, accept the Code of Practice on which it is based. We can not have one without the other, for the one is the basis of allowing the other.

In that context, the training of wire rope inspectors will become a critical issue for Canadian mining. It has been stated (Delorme, OMOL) that, in Canada, we are presently placing 90% of our reliance on our testing machines and 10% on visual inspections and the experience of our inspectors. In South Africa, it is stated that the relative reliances are about equal - i.e., 50%. We must move towards that and, if the SABS Codes are permitted in Canada, take immediate steps to assure that inspectors are properly trained and retained by the industry. Some have suggested that we could import South African expertise as it is needed. Others have suggested that we should send a core of selected people to South Africa for the full course of training. Still others have suggested that a mixed-mode approach might involve our people obtaining the hands-on training in Canada and then writing the South African certification examinations at the opportune time.

Likewise, it is essential that we develop Standards with respect to all aspects of the design, testing, use, and monitoring of wire ropes in Canada. If tests are to be used, either destructive or non-destructive, these should be standardized in such a way that anyone should be able to perform them anywhere, with the same results. Furthermore, it should be possible to record the data in such a way that the data from several successive examinations is shown on a full screen as parallel traces which are all referenced to a known and marked starting point on the rope. The settings of the instruments should be exactly the same on all successive examinations on the same rope. In simple English, steps must be taken to ensure that there is a comparability between the results of non-destructive tests on the same rope and that, in effect, an electronic file is created for every rope. The regulations could then be re-written to reflect this, as, for example, "rope must be tested in accordance with CSA G4", or with some Code of Practice yet to be written.

Regarding destructive tests, the writer has encountered strong feelings that the present state of technology in non-destructive testing is such that there remains a need to have "hard numbers" through which the deterioration, or loss of strength, of a mine wire hoisting rope can be tracked. Physical testing, therefore, remains as essential.

In some countries, including Canada, these numbers are determined though tensile tests to destruction of a sample of the wire rope. In others, notably Germany, pull tests are performed on samples of the individual wires used in rope constructions and the results "aggregated" into a calculated strength for the whole rope. As noted, one problem is that, as a rope ages, hardening of the steel will result in the individual wires becoming stronger. Thus, the calculated result is

likely to differ greatly from a test on a sample of the whole rope, which will show a reduction of strength. To address this problem, it has been suggested (HSL, 2000 05 24) that prescribed test methods should be determined for arriving at a calculated aggregate strength.

Regardless, of which means is used to determine the strength of a wire rope it is also believed that the dismantling of a sample of rope provides the only means of being able to look inside and to observe what is taking place.

Regarding non-destructive testing instruments, it has been stated that there needs to be a means of qualifying these based on known degradations in standard samples (Chaplin, 2000 05 25). There should be a standard test devised, with a standard rope, against which the performance of all instruments is judged. In one conversation (HSL, 2000 05 24), it was observed that different results can be obtained by using two different magnetic heads from the same manufacturer. One can, therefore, question the validity of the results. On the basis that magnets can deteriorate rapidly, it was suggested that the quality of these should be checked on a monthly basis.

Against this background it is clear that we will have no alternative in Canada but to place some reliance on the results of destructive tests until such time that it becomes certain that other critreia are more reliable or more accurate. The facts that destructive tests are referenced in many Canadian jurisdictions, and that the only laboratory present providing such results is OMOL's Sudbury Laboratory, has national implications for the industry. With the findings of this study in mind, it is clear to this writer that other providers of similar services would have to be found, or different financial arrangements would have to be proposed, were it to be decided that the present facility does not meet the financial or operational objectives of the Government of Ontario. For the immediate future, the industry must have recourse to destructive tests on samples of wire hoisting ropes. The key question is: who could, or should, provide these services, and at what price?

Next, from the visits and the literature, it is evident that electromagnetic instruments are qualified ("approved") in some jurisdictions. As mentioned previously, in Hungary (Geller et al, p. B-22), there are specifications for: (1) the minimum distances between defects that must be detected; (2) the calibration of instruments using samples of ropes of the same size and construction of the rope to be tested in the field; (3) the repetition of tests, at least twice, during field evaluations and; (4) the use of the same expert in performing both the field tests and the evaluations of the charts.

As regards instruments, it was also noted that the resolutions of these need to be improved It was stated that "there is a long way to go" to find the true picture in a wire rope since we are still a long way from being able to identify individual breaks in wires.

Further, using the latest in full-screen technology the results of any examination should be displayed in a format so that the results of each test can be displayed below those of the previous tests. The objective should be to develop means of presenting these data so that the entire progressive history of a wire rope can be examined concurrently. Against the background that there has been tremendous turnover in all aspects of the mining industry (including those firms that service it), it is increasingly common to hear the complaint that there is "nobody who knows

the rope". In the interests of the preservation of data, continuity, comparability, and, in the long run, the safety of miners, we need to ensure that this is done electronically.

As mining proceeds to greater depths in Canada, and as the life of the wire rope will become more and more important it is essential that steps should be taken as quickly as possible to ensure that all non-destructive testing results are obtained, recorded, and examined in a consistent manner which will permit comparisons without any doubts at all, and stored and archived in a permanent archive within the control of an appropriate body. In this writer's opinion, it would be entirely reasonable for the Ontario Ministry of Labour to require that new standards and practices be put in place and that it be furnished with electronic copies of all tests performed on all ropes within the province after a certain date.

Regardless of the approach, the blunt fact is that, in making such a significant change in our mining culture we can not take, and can not be seen or perceived as taking, any steps which would create the impression that mining health and safety is being compromised. This writer's view is very firm that the training, in its entirety, is absolutely essential. There must be no short-cuts. Either the mining industry, or those in the commercial testing business must consider this as an investment in their future business and must be prepared to fund it in the same way that any technical innovation is funded.

Going beyond the immediate future, then, if mines are to be developed at greater depths, it is a reasonable assumption that mining technology must continue to advance and to test new frontiers and limitations. As regards wire hoisting ropes one can wonder how far the art and science can be pushed. Surely, as in the design of the Blair (BMR) hoist, if the problem, lies in the cross-sectional area of the cable that is available to hoist the load, the solution must lie in providing more cross-sectional area. Perhaps one should ponder the possibility of adding still further ropes to the system? What are the reasons, for example, why double twin cables could not be used? If one of the impediments is the size of the drum, then, again, let us consider larger drums, etc.

Mine hoisting plants in Canada must evolve along the line of the specifications that are required in South Africa for Class 1 Winders. This will include continuous monitoring of the wire rope, with pre-set limits on stresses, alarms to indicate when these have been exceeded, and control measures that can be taken to keep practices within acceptable limits. The cost of hiring an operator to do this could be justified on the basis that this would probably pay for itself if the life of a rope could be prolonged by three to six months. There is a clear need to have a person sitting in front of a screen to monitor the wire rope. At the same time, any pressures to assign duties additional to those of a rope inspector should be strongly resisted.

The wire rope presents still further challenges through considering the possibilities of changing a basic manufacturing technology which has changed very little, in respect of maintaining a constant mass per unit of length, over the years. As any fly fisherman knows, part of the solution of delivering a small object (the fly) over a great distance lies in a tapered line. Would it not be possible to design tapered hoisting cables, or, failing that, to construct cables, so that the mass is tapered, with the lightest part at the bottom of the shaft where the least rope is required to suspend the load? In South Africa these are referred to as "stepped mass" ropes. The principle is that steel wires are progressively replaced with fibre towards the front end of the rope, where

lesser strength is required. For winding purposes, the key is to maintain a uniform cross-sectional profile. Other possibilities include manufacturing ropes of variable lay lengths in order to reduce the moments within the rope (i.e., the tendency to cause rotation). Thus, the lay length could be shorter at the bottom, or front end, and longer at the drum, or back end.

Canada needs to develop not only world-class experts in the testing of wire rope but also world-class experts in driving wire rope technology forward!

In the meantime, the choice of the rope that is most suitable for deep mining seems to be the conventional six-strand triangular-strand constructions. There are several reasons for this. First, there are lesser losses of strength due to spinning. Second, the behaviour of such ropes is both well-known and understood. Third, the criteria for replacement are also clear. Fourth, such ropes tend to deteriorate from the outside and this provides visible evidence. Fifth, and finally, such ropes are both easier to inspect and to assess. To the question that conventional ropes deform at great depths with changes in lay length resulting, the response was that at least the changes are known and can be measured and assessed (Dohm & Borello, 2000 04 17).

On the "other side of the coin" it was said that, while non-spin ropes are very stable at great depths, the problems are that these wear very quickly (Dohm) and that there are no means of looking inside the rope to detect the internal conditions. Deterioration of the rope is from the inside and all of the non-destructive testing instruments that are presently available can not do this (Borello).

With that as background, it is clear that there are roles for both visual inspections and non-destructive means of evaluation as tools in the "front line" of rope inspections. The first provides the most definitive means of evaluating what is happening to the outer surface of the wire rope. It is an indispensable tool in evaluating whether or not the rope has sustained damage from excessive wear, surface corrosion, broken wires or strands, or objects having fallen against it.

Electromagnetic non-destructive tests methods, on the other hand, provide a means of going beyond this and having an indication of what may be taking place inside the rope. Notwithstanding this, it is clear that there are many problems associated with the methods. These include: (1) a lack of training of operators; (2) a perceived inconsistency of performing tests and in recording observations; (3) a lack of standardized procedures; (4) a lack of comparability of results, principally between tests on the same rope; (5) a lack of standardized methods of both qualifying and calibrating instruments.

Against this background, it is clear that standards should be developed for the calibration of instruments. Further, training needs to be developed in order to improve the competencies of operators.

For all of these reasons, there are strong feelings that test results are valuable, but only up to a point. Beyond that point, other means of evaluation, principally destructive tests and all that accompanies these, including determinations of elongation and torsional resistance and disassembly, are considered to be essential. We need to recognize that there is an upper limit to non-destructive testing technology, and "there are things that people can see as well as not see".

In summary, all of the means of evaluation that are presently available to us are valuable but the state-of-the-art is not at the point where any single component can be dispensed with.

The next question that arises is whether or not it is possible to move towards safety factors which are more reflective of the present standards of wire rope technology, hoisting practices, and means of evaluating the in-situ conditions of wire ropes. As the visits have shown, the requirements in the European countries visited are very conservative in comparison with those in use elsewhere. It is to be recalled that the safety factor at the drum, to be used for a drum winder is 6.5 in Great Britain, 8.5 for a 1000 metre shaft in Germany, and 7.5 for a 400 metre shaft in Poland (all of the examples are for shafts in which personnel are transported). To this should be compared the factors of 4 and 5 in use in the United States of America and Canada, respectively. At the other end of the spectrum will be the factors of less than 4 which will be used in South Africa as hoisting is from greater depths using Class II winders.

In the context that a Factor of Safety at the sheave, of 4, has been is use for some time in the United States of America, it appears that Canada remains quite conservative in its use of a factor of safety of 5. Nonetheless, it was emphasized in the conversation at Wire Rope Industries (2000 03 21) that the Canadian mining industry has always been inherently conservative and that conservatism is certainly de-rigeur as regards a choice of safety factors.

Nonetheless, the factors of safety in use must be viewed in an historical perspective. All of the European requirements are based on long traditions of hoisting. As mentioned, and as an example, the factor of safety of 6.5 that is used in Great Britain originated in the days of hoisting plants that were powered by steam. The ways in which these were operated was very crude by present standards. Thus, higher factors of safety were required in order to protect against accidents. Similar considerations probably underlie the current requirements in Germany and Poland.

Nonetheless, in taking the present improved state of mining practices and wire rope technology into account, it is acknowledged that there is probably room to move towards reduced factors. In doing so, however, it becomes extremely important that one must know the condition of the rope at all times. Both increased inspections and better means of evaluations become critical to the process.

During the writer's visits, one aspect that became very clear is that there is very little information available concerning the successes and failures that have resulted from the practices in the several countries, or concerning rope failures. The best information that was made available to the writer was that which was produced in the Province of Ontario, and which showed that there has been about one rope failure each year, for the past fifty years (references). As noted earlier, it has been several years since there has been a fatality due to a broken rope.

As the result of this study, the writer believes that every effort must be made to compile information on rope failures and near-failures, so that one may be able to assess the consequences (if any) of the practices in place in the different jurisdictions.

As the result of the conversations with the leading experts on three continents it became clear that, in most of the mining regulations, all wire ropes are considered to be equal. Regardless of whether or not a rope is six-stranded, or of non-spin construction, or of any other construction, the same safety factors apply.

The problem, as with safety factors, is that the technology of wire rope manufacture has evolved rapidly while the regulations have not.

As noted in this report, however, the problem has been addressed through the development of rope retirement criteria which are particular to some of the rope constructions in use in the Republic of South Africa (SABS 0293:1996). It has also been discussed by McCain (references).

In the future, it is believed that similar developments must take place in all of those principal mining jurisdictions in which several constructions of ropes are used. At present, South Africa is leading the world in this respect. The others would be well-advised to follow.

Likewise, inspection practices must be changed. Throughout the visits it was emphasized that all three means that are presently at our disposal - visual, destructive tests, and non-destructive tests - require improvement. While some are perfect in principle, none are perfect in practice.

Visual examinations, for example, are required on a daily basis. This writer's impression was that while great care and diligence are taken in South Africa, the practices elsewhere may require substantial improvement. Often, particularly in North America, it was noted that such examinations tend to be cursory, at best. The writer is of the opinion that a standard should be developed in which all aspects of the procedure, including the setup required, the speed at which the rope travels during an inspection, and the lighting conditions required (to name but a few) are specified. Literally everyone stated that this is one of the single most important aspects of rope inspections.

The testing of wire ropes, both destructive and non-destructive, requires further examination. One of the advantages of destructive tests is that well-recognized procedures, which are well-documented, have been developed during the past years. Up until the recent past, however, there has been much variability in the ways in which non-destructive tests have been performed. At the risk of being perceived as being unfair to those in the field, several persons have said that all of the present non-destructive electromagnetic testing methods are uniformly unsatisfactory and that claims are made for all of these that are unsupportable. Others have reported that there have been few advances made in the technology in the past forty years and that there is a clear need for technical innovation in the development of new and improved instruments.

Notwithstanding these criticisms, every single person interviewed stated that non-destructive testing methods are indispensable and that the problems lie neither in the scientific instruments nor in the principles on which these are based, but, rather, in the lack of standardized procedures for the qualification and calibration of instruments, in the lack of standardized operating procedures, and in the variability with which inspections are made. Electromagnetic methods are the ONLY means of making an attempt to assess the conditions in the interior of most of the length (but not all) of a hoisting rope. These are essential, but improvements are required.

On the positive side, a new (American Society for Testing and Materials) ASTM Standard, E1571-96, was published in 1996. If followed, this should result in the elimination of the causes of much of the criticisms.

With a view towards the future, and from the point of view of continuous monitoring, the technical challenge that confronts us is to obtain instantaneous information on the structural quality of a steel wire rope which is being passed before us at high speed, coated with greases, grime, and debris, and which is most often being viewed under difficult atmospheric conditions and very poor visibility. For all of these reasons, it will be difficult to develop reliable optical methods.

As a final note on this aspect, it has also been stated frequently that neither destructive nor non-destructive methods of evaluation provide assessments of the strength of a hoisting rope in what are probably the most critical areas - at the cappel, and at the sheave wheel when the full length of the rope has been wound out. Each method, together with visual testing, have advantages and disadvantages. All must be used together in order to provide the most accurate assessment that is possible of the quality of the wire rope.

In this context, the training and accreditation of wire rope inspectors will become an important issue in the future. Beyond any question, the South Africans are among the world leaders in this respect though the implementation of the requirements of the new SABS Codes of Practice. There will be a benefit for Canadians from this inasmuch as those same codes became applicable to a part of Canadian mining practice when these were enacted in Québec in mid-2000 (references). In the immediate future the operators of a Canadian mine, Agnico Eagle's Laronde mine, near Val d'or, Québec, will be obliged to follow the provisions of the SABS Codes as the shaft is deepened to 7800 feet in order to permit the exploitation of deeper parts of the orebody. Concurrently, an employee of Labcan, Vincent Rodier, is participating in training in South Africa for qualification as a Level I Wire Rope Inspector. Both of these are trail-blazing moves which are harbingers of the technical challenges which will confront Canadians as we move towards the development of mines at great depths.

At present, the approach has been to import the technology and practices from elsewhere; namely, South Africa. In the future it must be decided if the demand is sufficient to develop standards and training which are best-suited to the particularities of Canadian conditions. In the writer's view; the question is not "whether" but "when". It will be up to the industries concerned (i.e. mining and testing) to determine when our particular conditions drive us towards these developments.

19. Summary and Conclusions

As the result of this study the writer has acquired a much deeper appreciation of the complex machine that is wire rope. It is a machine in every sense of the word. It is comprised of a framework of both fixed and moving parts. As it is both wound and unwound from the drum during mine hoisting it stretches and relaxes. The differential movements of both the wires and the strands made from these, and the core, often of a different material, can cause the rope to function as a pump during winding operations. Its very flexion can cause water, and dirt, and grime, to be draw in and pressed out. The rope also performs work as men and materials are hoisted and lowered to the mine workings beneath the headframe.

In the first instance, the quality of the rope is utterly dependent upon the qualities of the materials of which it is made and the quality controls which surround its manufacture. During the study, the writer encountered both manufacturers and governments which insist that the wire and the rope from which it is made shall be produced to certain standards. The writer is in complete agreement with this and is of the opinion that an insistence on such standards would virtually eliminate the possibilities of sub-standard ropes from entering the country.

Secondly, since all ropes are manufactured to order, it seems clear that the possibility exists that each and every rope may have slightly different characteristics. Thus, it would be desirable to require a standard Certificate of Manufacture, on which would be recorded the initial properties and characteristics of the rope. Records-keeping (or the lack of it) emerged as an important issue during the study. The writer's view is that there should be a file for each rope, and that the complete history of the rope should be contained therein. There is no reason why this can not be done electronically and to a standard format.

In this project, the most important objective was to study the key practices that are used around the world in determining the criteria that are used to decide when wire hoisting ropes should be removed from service. During the writer's visits in a number of countries (Canada, the United States of America, the Republic of South Africa, the United Kingdom, Germany, and Poland) and from documentary and verbal evidence from others (Australia, Hungary, and Sweden), it was determined that, even though practices have evolved locally, there are a number of common threads.

First, it was generally acknowledged that visual inspections, while essential, are often neglected. The reasons most often encountered was that downsizing in the industry has resulted on too many demands being placed on too few people – with the result that some jobs receive cursory attention.

Second, destructive testing was generally acknowledged as being essential – for the reason that it is the only means through which "hard numbers" can be obtained for the strength of a wire hoisting rope. Even in those jurisdictions which do not require such tests it was stated that, if they did, the requirement for the test would not be abandoned. The view is that we need all of the tools that are available to us in determining whether or not a wire rope should be replaced.

Third, non-destructive tests were also seen as being essential – for the reason that, apart from visual methods, these provide the only other means of assessing the condition of almost the entire length of a rope. The added advantage, of course, is that these provide the only means of "looking into" the rope. Regardless of the difficulties with destructive tests, and these are detailed in this report, there are simply no better methods which are available to us at present.

Fourth, it is clear that the quality of the rope is utterly dependant on the way in which it is used (and abused). The writer has examined both the Codes of Practice, from South Africa, and a part (7) of the Guidelines for Safe Mining, from the Province of New South Wales, in Australia. Both are impressive, and it struck the writer that both were produced by similarly-sized, once-sister Dominions of the British Empire!

One of the principal conclusions of this study, then, is that we, as Canadians, would be well-advised to design a similar Code of Practice for all aspects of the operations of mine hoisting plants.

This would have far-reaching implications.

First, and particular to the subject of this study, it would be desirable to examine all of the criteria which are used to determine if a wire rope should be rejected, and of the means that are used to enforce these decisions. The writer is convinced that separate criteria must be developed for each and every major type of rope construction that is used in Canadian mining. Six-stranded and locked-coil ropes are entirely different in their construction, performance, and means of degradation. The criteria for rope replacement must reflect this.

Second, and also particular to this study, the writer concludes that standards should be developed for all aspects of the evaluation of wire ropes. These range from the simplest, visual inspections, to the most complicated, non-destructive testing. Standards should be established for: the ways in which all tests should be performed; the conditions under which such tests should be performed; the means that are used to both qualify and certify test instruments and instrument operators; the ways in which data is acquired, interpreted and archived; and the training and experience required of accredited wire rope inspectors. It is clear that there is a need for all of the means of evaluation that are presently at our disposal. Each contributes to our understanding of the functioning of a very complex machine. We have not yet reached the point when any can be replaced by another.

In the preceding report, it was mentioned that several persons had described the present situation as "unregulated chaos". The writer's view is that this is unfair to those who are working in this field. It is, however, reflective of the situation that can arise when standards and procedures do not exist.

Next, it was also mentioned that evidence is accumulating that suggests that unexpected results may be awaiting us as we proceed towards installing ropes in "ultra-deep" shafts. Mine operators and regulators need to be aware of "how the machine will function" as the depths become greater and the ropes much heavier.

Finally, one of the South African Codes of Practice (SABS 0294:1996), still in draft form, refers to the "Performance, Operation, Testing and Maintenance of Drum Winders Relating to Rope Safety". In essence, the key principle is that long ropes can be used in "ultra-deep" single-lift shafts provided that (and only provided that) operations are controlled to the extent that dynamic stresses are literally eliminated. Under these circumstances, the peak stresses that will result at any time are no greater, and probably less, than the peak stresses that result in shallow shafts today under conditions of loading conveyances and emergency braking.

If we are to mine at much greater depths in Canada, and to exploit our mines through "ultra-deep" shafts, it is important to recognize that one can either reduce dynamic stresses to the point at which these will be unable to cause catastrophic damage to a rope, or one can reduce the loads to be hoisted to the point that this can not happen either. The choice will be up to operators but there can be no compromise.

20. Recommendations

With all of the above in mind, this writer recommends THAT:

1) Until such time that it has been clearly demonstrated that there are clear redundancies between the criteria used in judging whether or not a mine hoisting rope should be rejected, all of the criteria presently contained in the Ontario Regulations should be retained.

   A criterion, and the means to assess it, should not be discarded until such time that it can be proven clearly that it is redundant.

2) There should be a continuing compilation and assessment of the wire rope retirement criteria used in the major mining jurisdictions, and a dialogue should be commenced with a view towards establishing the exact relationships between these.

   In particular, there is a need to establish the relationships between Loss of Metallic Area (LMA), as measured by non-destructive electromagnetic means of evaluation, and Loss of Breaking Strength (LBS), as determined by destructive tensile tests, and the effects of various rope constructions and the means of degradation on these. There is a need for research in this area.

3) In the knowledge that the effects of interstrand nicking, wear, and corrosion will likely be different for each type of wire rope construction, consideration should be given to developing separate retirement criteria for each wire rope construction – as has been done in the Republic of South Africa and has been recommended in the United States of America.

4) Standards should be developed for all of the various aspects of wire rope inspection practices, including the manner in which these are to be performed and the conditions which are provided by mine operators.

   In particular, attention should be given to: (1) the diligence expected of wire rope inspectors; (2) the set-up and working conditions to be provided by mine operators; (3) the speed and which a rope should be inspected; (4) the ambient levels of lighting required; (5) the records to be maintained; and (6) the sign-offs required, including the signatures of senior on-site officials.

5) Standards be developed in respect of all of the tests and means of evaluation which are required to determine whther or not a wire hoisting rope should be discarded.

   These should include not only destructive and non-destructive tests but also subjective and visual means of evaluation. Reference could be made in the Ontario Regulations to the various Standards and Codes of Practice which are recognized – such as ASTM (American Society for Testing and Materials), CSA (Canadian Standards Association), etc..

The Standards should also include standards for test instrumentation and the means by which these should be calibrated.

6) Standards be developed for the training of wire rope inspectors to levels which are deemed to be acceptable to the regulators.

Training should be provided to all of those who perform such evaluations – from those who perform daily pre-operating inspections at the headframes to those who perform the more sophisticated tests used to assess the state of a wire hoisting rope against the criteria which are used to determine whether or not it should be rejected.

As above, reference in the Regulations could be made to existing Standards and Codes of Practice which are recognized through the Ontario Regulations.

7) Consideration should be given to the development of a Canadian Code of Practice for the design, operation, and inspection of mine hoisting plants.

In this respect, the Province of Ontario might wish to lead in the formation of a Task Force, on which parties from other jurisdictions wishing to participate could be invited to participate.

In the final analysis, the conditions under which Canadian mines are operated are sufficiently unique, and mining technology has advanced to the point where a "Made in Canada" Code of Practice and Standards should be developed. This Code of Pratice should be aimed at advancing Canadian practices to the level of, and possibly beyond, those which have been developed in the most progressive mining jurisdictions around the world.

This will become essential as we mine orebodies at greater depths and under more adverse conditions.

The safety of our mineworkers is paramount. We must now lay the groundwork for what lies ahead.

Appendix I - Persons and Places Visited, Conversations Held

Acknowledgements

"The author wishes to express his gratitude to the several organizations and people, listed here, who provided much of the information on which this report is based. Their collaboration and generous commitment of time to the discussions is deeply appreciated."

1) 2000 03 21 (in Pointe-Claire, Québec)

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Mr. McIvor retired in mid-May and was replaced by:

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Mr. Polkinghorne also attended the meeting.

4) 2000 03 28 (in Onaping, Ontario)

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Mr. Sheldrake retired in mid-May, and was replaced by:

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Mr. Adams also attended the meeting, as did Terry Skinner. All three have been involved in the design of the Onaping Deep hoisting plant.

Terry Skinner,
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8) 2000 04 03 (in Tridelphia, West Virginia)

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Mr. Bokosh attended this and the subsequent meeting at Bruceton, Pennsylvania).

9) 2000 04 03 (in Bruceton, Pennsylvania)

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10) 2000 04 04 (in Bruceton, Pennsylvania)

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11) 2000 04 11 (in Johannesburg, Gauteng, South Africa)

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The meeting was held at the Wire Rope Laboratory, on CSIR's Cottesloe Campus. Dr. Olmstead is CSIR's expert on non-destructive testing.

12) 2000 04 11 (in Johannesburg, Gauteng, South Africa)

Pat Willis, Pr. Eng.,
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Frieder Hecker,
Mechanical Testing & Measurement (Pty.) Ltd.,
Box 369, Rayton, 1001,
Republic of South Africa,

The meeting was held at CSIR's Landau Terrace (Middle) Campus.

Messrs. Laubscher and Hecker are industry experts who participated in drawing up the South African Standards.

13) 2000 04 13 (at Elandsrand Gold Mine, Fochville, North West State, South Africa)

Mike O'Brien, Project Manager, Mining Systems,
CSIR Miningtek
(see Entry Number 11, above)

Sarel Mostert, Rope Condition Assessment,
Senior Machinery Inspector,
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Jani Grobbellaar,
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On 2000 04 13 and 2000 04 14, the writer, in the company of Messrs. O'Brien and Mostert visited a number of deep mines in the Witwatersrand area. All have installed Blair (BMR) hoists as well as a number of other conventional drum hoists. The "shaft banks" are among the largest in the world, with as many as 12 ropes installed at a single location.

14) 2000 04 13 (at Moab Knotsong Mine, Formerly Vaal Reefs, Number 11 Shaft, Vaal Reef, Free State (formerly Orange Free State), South Africa)

Mike O'Brien (see Entry Number 11, above)

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Appendix III - Some Notes on the Mine Visits

Elandsrand Gold Mine, Fochville, North West State, South Africa, 2000 04 13

At Elandsrand, the twin-drum Blair Multiple Rope (BMR) hoists are installed in-line with a mechanical geared coupling. One drum is over-wound whilst the other is under-wound. The hoists are equipped with conventional shoe brakes. The depth of the shaft is 2300 metres, or 7546 feet.

The hoisting ropes are a 48 mm diameter six-strand construction. The compensating sheaves are installed at the conveyances. Electromagnetic inspections of the ropes are made every six months.

The Elandsrand mine is also the site of an experiment to test the possibilities of reducing the existing safety factors. This is taking place in a shaft which is used for hoisting rock only and is being done under very closely monitored conditions. In the first part of the experiment, a conventional 53 mm diameter wire rope, at a standard factor of 4.5 was run until replacement was required. It was then replaced with a 48 mm diameter rope at a factor of 4.0. This rope was replaced after 157,000 cycles by a 43 mm diameter rope, with a factor of 3.5. It is still being run after 250,000 cycles and it was noted that "it is doing well". Throughout the tests the load on the rope and its condition are being continuously monitored.

In addition, there is a conventional double-drum hoist for services. Thus, six ropes enter the headframe.

Moab Knotsong Mine, Formerly Vaal Reefs, Number 11 Shaft, Vaal Reef, Free State (formerly Orange Free State), South Africa, 2000 04 13

The Moab Knotsong hoist installation features twin Blair Multiple Rope (BMR) hoists which are installed in parallel alignment but with a staggered arrangement. Rather than a mechanical coupling between the hoists, as at Elandsrand, the hoists are coupled electrically. The installation is one of the most sophisticated in the world, with it being possible to run the hoists either independently or coupled together. Both drums are over-wound and both are equipped with disc brakes.

The hoisting ropes used are a 52 mm diameter non-spin construction. Compensating sheaves are installed in the headframe.

In addition, there are two other conventional double-drum hoists. Both are used for hoisting personnel and materials.

In this instance, eight ropes enter the headframe. There is also a second shaft, for services, close-by. At some stage in the not-too-distant future the Moab Knotsong shaft will become the deepest single lift shaft in the world. Presently, the shaft is 10 metres in diameter and 2340 metres (7677 feet). Plans are being made to sink a seven metre extension to a depth of 3150 metres

(10334 feet). This will be done by installing a cap at the bottom of the shaft and executing the sinking from an interval winze. During this period production and sinking will continue concurrently. Afterwards, the cap will be removed and the ropes replaced. The company wishes to commence hoisting from this level by July, 2001 (Dohm, 2000 04 17).

At some stage it is planned to extend the shaft to 4000 metres (13123 feet). It will then be far deeper than any other single-lift shaft in the world.

Mponeng Mine, Formerly Western Deep Levels, South Mine, Western Levels, North West State, South Africa, 2000 04 14

The Mponeng Mine has one of the most extensive winding plants that this writer has ever seen - with East and West Winder plants on opposite sides of the main shaft.

In the East Winder there are installed a conventional under-wound/over-wound mechanically-coupled BMR winder with spring-activated shoe brakes, as well as two double-drum conventional hoists - with one providing services to the Main Shaft and the second to the other.

This arrangement is more-or-less mirrored in the West Winder, with its BMR installation and double-drum hoist.

All-in-all, twelve ropes enter the headframe of the Main Shaft while the remaining two enter the headframe of the auxiliary services shaft. There are thus 14 ropes.

South Deep Mine, Fochville area, North West State, South Africa, 2000 04 14

Formerly owned by JCI (Johannesburg Consolidated Investments), this property was acquired by a partnership which includes Canada's Placer Dome organization about two years ago. It is presently being developed as one of the world's deepest mines. On the date of the visit both the Main shaft and a close-by auxiliary shaft were being sunk. The Main shaft had then attained a depth of 2700 metres (8858 feet) of a planned 3000 metres (9842 feet). The auxiliary shaft will be sunk to about 2700 metres (8858 feet) and is lagging slightly behind the main shaft in terms of the depth to which it is being sunk.

The Main shaft is being sunk at a diameter of 10 metres, with temporary support being provided by shotcrete. The finished diameter will be nine metres. During the tour, the writer had the experience of descending beneath the collar to watch the kibbles (buckets) filled with shaft muck being hoisted. It was an unforgettable experience to look down the world's deepest single lift shaft - an unfinished hole almost 9000 feet deep!

During the visit there was also an opportunity to visit the stage winder which is being used during the sinking operation. This is very much an unusual installation in the sense that an exemption granting lower-than-normal safety factors has been permitted during a sinking operation - provided that strict attention is paid to observing the new Code of Practice (SABS 0294). It will, nonetheless, be necessary for the contractor to change the stages ropes in the immediate future. Since the exemption has permitted the shaft to be sunk to a greater depth than

originally planned, i.e., 3000 metres rather that the intersection of the reef at 2700 metres, the result was that the ropes originally ordered were not sufficiently long to reach the extended depth.

It was noted that, since four stage ropes are required for sinking, each drum was wound with over 12 kilometres of 48 mm diameter non-spin rope on it. With a total weight of 110 tonnes per reel it was noted that one of the limitations on deep mining will be the ability to physically deliver the weight of wire rope that will be needed to sink the shafts.

The headframe of the Main shaft is 293 metres (961 feet) high. This was, for a period the highest headframe in the world. Recently, however, the construction of a 300 metre (984 feet) headframe at Palabora, has caused the record to fall.

Another unusual feature of the development of South Deep was that the shaft pillar was excavated to a radius of 350 metres before shaft sinking began. This was accomplished by gaining access to the area from a neighbouring mine, the South mine, and mining the shaft pillar area out. It was mentioned that the area was then filled with cemented fill (4% cement). During the sinking of the Main shaft through the pillar, it was noted that 100 mm of shotcrete was used for temporary support and that the backfill in place had only consolidated by a very small amount (4%). Additionally, a "suspended tower" was installed in the shaft to provide reinforcement to that part passing through the zone which had been affected by the pre-mining of the shaft pillar. The tower extends from a depth of 2347 metres (7700 feet) to 2733 metres (8966 feet).

It was noted that skipping will involve two 12-tonne aluminum skips, each with a payload of 31 tonnes. Each of the two ropes for the Blair (BMR) hoist will be 49 mm in diameter and comprised of six strands of 32 wires of triangular cross-section.

The main winder at South Deep is also a BMR. It is the most sophisticated winder in the world since it includes several completely unique features. First, in order to reduce the fleet angles at the headframe, the winders were each rotated towards each other by 1.5 degrees. The shafts were then coupled together with an enormous universal coupling. Secondly, the BMR is also being used to hoist the kibbles from the shaft bottom. To this end, each BMR drum is half-loaded with a single rope being wound into Le Bus grooving. Third, load cells are used in the headgear to monitor the loads on the ropes at all times. This is on a visual display which is viewed by the Winder Operator. Whenever any of the conditions as dictated by the Code of Practice (SABS 0294) are exceeded the display changes from black characters to red. Thus, the Operator is aware when either loads, speeds, or dynamic stresses in the rope may be excessive.

This condition occurred while the display was being viewed. The contractor noted that this was due to water being pumped into the kibble on top of the broke waste (in order to clear it from the shaft bottom) and that the remedial action to be taken almost immediately would be to replace the kibbles with ones of smaller capacity. (It was observed that the load was 28.3% of breaking strength as opposed to 25%. This is permitted under the Code of Practice but not on a continuous basis).

It was also mentioned during the visit that there have been problems with the hoisting ropes during the sinking operations. It was stated that, once the length of a rope exceeds about 1800 metres (about 5900 feet) something seems to happen such that the condition of the rope can not be predicted.

In this case, two ropes had been rejected because of broken strands. Slack (proud) strands and waviness had been observed at the front end of the rope and it was suspected that the problems were being caused by a slippage between the core and the strands of the rope. During hoisting the writer also observed severe oscillations in the rope as the kibble approached the collar. These were estimated (and confirmed) as being of the order of one metre or more.

Table 1

Mine Hoisting in Several Countries

Item	Canada (Ontario)	USA	Republic of South Africa	United Kingdom	Germany	Poland
Number of Drum Hoists	300	500	700			A few
Number of Friction Hoists	43	35	21	16	N/A	460
Maximum depth of operations (metres)	2300	1800	4000	1100	1000	1000
Employment underground	30,000		400,000		60,000	
Fatalities in shafts	0 (10 yrs)	0 (a long time)				

Table 2

Safety Factors in Several Countries

Safety factors for	Canada (Ontario)	Canada (Quebec)	USA	Republic of South Africa	United Kingdom	Germany	Poland	Australia (NSW)
Drum hoists – sheave	5	5	7.0 – 0.001 L (ft)	4.5	6.5		7.5 – men 6.5 – output	7.5 – 0.001 L (m)
Or, not less than			4.0, for ropes, 3000 ft +>					See text
Drum hoists – cage	8.5	8.5		8.0				
Drum hoists – skip	7.5	7.5						
Friction hoists (x – yL)	8.0 - 0.00164 L (m)	9.5 – 0.00246 L (m)	7.0 – 0.0005 L (ft)	8.1 – 0.00135 L (m)		9.5 – 0.001 L (m) – men, 7.2 – 0.0005 L – material	See text – formula are depth dependent	See text for formulae
Or, not less than	5.5		5.0, for ropes 4000 ft +	6.75 (1 rope) 6.19 (2 or 3 ropes) 5.62 (4 or more ropes)				7.5 (1 rope) 6.9 (2 or 3 ropes) 6.3 (4 or more ropes)
Balance, tail ropes		7.0	7.0	5.0		6.0	6.0	
Guide, rubbing ropes		5.0		5.0		4.5	5.0	
Stage ropes				4.5		7.5		

Table 3

The Inspectorates in the Countries Visited

Organization	Canada (Ontario)	USA	Republic of South Africa	United Kingdom	Germany	Poland
Government	X	X		X		
Para-Government			X			
Private Industry					X	X
Fees for Service	X		X	X	X	X

Table 4

Summary of Inspection Practices in Several Countries

Practices	Canada (Ontario)	Canada (Quebec)	USA	Republic of South Africa	United Kingdom	Germany	Poland	Australia (NSW)
Daily inspections prior to work	Yes	Yes		Yes	Yes		Yes	
Weekly inspections		Yes					Yes	
14-day inspections			Yes					
Monthly inspections	Yes			Yes, not > 45 days	Yes			
45-day inspections		Yes					6 weeks	
Biannual inspections	Yes		Yes					
Destructive tests required	Yes		No	Yes				Yes
Frequency of testing	6 mos. after inst.; then 6 mos.	12 mos. after inst.; then 6 mos.	6 mos.	6 mos. front 3 mos. back				6 mos. both ends, see text
Non-destructive tests required	Yes		Yes	Yes				Yes
Speed of winding during inspection				2 m/sec	5 ft/sec			
Lighting conditions during inspection					Yes			
Full report of all tests in dossier			Yes	Yes		Yes	Yes	

Table 5A

Summary of Regulations for Non-Destructive Testing in Canadian Jurisdictions in 1988

(After Geller et al. (See references))

Requirements	Ontario	New Brunswick	Québec	Manitoba	Saskatchewan
Requirement for competent inspector	Yes	Not specified	Approved organization	Not specified	Yes
Requirement for Electromagnetic device	Yes	NDT method	NDT method	NDT method	Yes, or other
Requirement for Approved device		Yes	Yes	Suitable	Yes
Hoisting ropes: months after installation to 1st inspection	6	6	12 (drum)	6	6 (drum & friction)
Tail, guide, rubbing ropes: the same	12	12	12 (friction)	12	12 (friction)
Hoisting ropes: frequency in months thereafter	4	6	6 (drum & friction)	4	6 (drum & friction)
Other ropes: frequency in months thereafter	8	Not specified	Not specified	8	12 (friction)
Hoisting ropes: shorter intervals if 10% LBS anticipated	Yes	Not applicable	3 mos. when LBS ≥ 6%	Yes	Not applicable
Other ropes: shorter intervals if 10% LBS anticipated	Yes	Not applicable	Balance ropes 3 mos. when LBS ≥ 8% Guide 7 rubbing ropes 3 mos. when LBS ≥ 15%	Yes	Not applicable
Other ropes: frequency in months after LBS exceeds 5%	4	Not applicable	As above	4	Not applicable
Records to be sent when losses exceed 7.5%	Yes	Not applicable	Not applicable	Not applicable	Not applicable

Table 5B

Summary of Regulations for Non-Destructive Testing in Several Countries

Requirements	Canada (Ontario)	Canada (Quebec)	USA	Republic of South Africa	United Kingdom	Germany	Poland	Hungary	Australia (NSW)
Requirement for competent inspector	Yes			Yes		Yes		Yes	
Requirement for Electromagnetic device	Yes	Yes				Suitable		Yes	
Requirement for Approved device						N/A		Yes	
Requirement for re-calibration			Periodically	12 mos.					
Hoisting ropes: months after installation to 1st inspection	6	12				12 1 for EM	1		
Tail, guide, rubbing ropes: the same	12	12				24 (tail) 60 (others)			
Hoisting ropes: frequency in months thereafter	4	6				To be specified	6		
Other ropes: frequency in months thereafter	8	6				To be specified			
Hoisting ropes: shorter intervals if 10% LBS Anticipated	Yes	Yes, 3 mos. when ≥6%				N/A			
Other ropes: shorter intervals if 10% LBS Anticipated	Yes	Yes, 3 mos. when ≥8%				N/A			
Other ropes: frequency in months after LBS Exceeds 5%	4					N/A			
Records to be sent when losses exceed 7.5%	Yes					N/A			

Table 6

Summary of Rope Retirement Criteria in Several Countries

Rope Retirement Criterion	Canada (Ontario)	Canada (Quebec)	USA	Republic of South Africa	United Kingdom	Germany	Poland	Hungary	Australia (NSW)
LBS, hoisting rope, % of original	90%	90%	90%	90%	90%	85%	85%	85%	10%
LBS, multistranded bal. rope, % of original	90%	88%, cable deformé				70% (FS≥5)			
LBS, single layered balance rope, % original	85%	75%, cable non-deformé				70% (FS≥5)			
Guides, rubbing ropes, % original	75%	75%				85%			
Extension, % original	≤ 60%	≤ 60%		Plastic strain ≤0.5%		Not spec.			≤ 60%
Electromagnetic Tests, Loss of Metallic Area	Yes		Yes	Yes	Yes	Yes	Yes, ≥20% hoist, ≥30% balance	Yes,	Yes, ≥10%
Broken wires, ≥ than % per lay length (or other length)	≥5%	≥5%	≥ 5%, or ≥15% in 1 strand	Yes Construction. Dependent		Yes, per critical length 15 X dia.	No	Yes, ≥ 10% in 10 m. length	≥ 5%, or ≥ 8% for uniform dist.
Lay lengths, increases or decreases				Yes, ± 12%					
Loss of crown wires	N/A		Yes, ≥ 33%		Yes, ≥ 33%	N/A			
Reduced torsion						N/A			
Loss of Diameter			Yes, ≥ 6%	Yes			Yes		Yes
Loss of depth, outer wires						40%			
Corrosion			Yes	Yes	Yes, ≥16%				
Damage to Structure			Yes	Yes					
Disassembly	Yes			Yes					

ILLUSTRATIONS

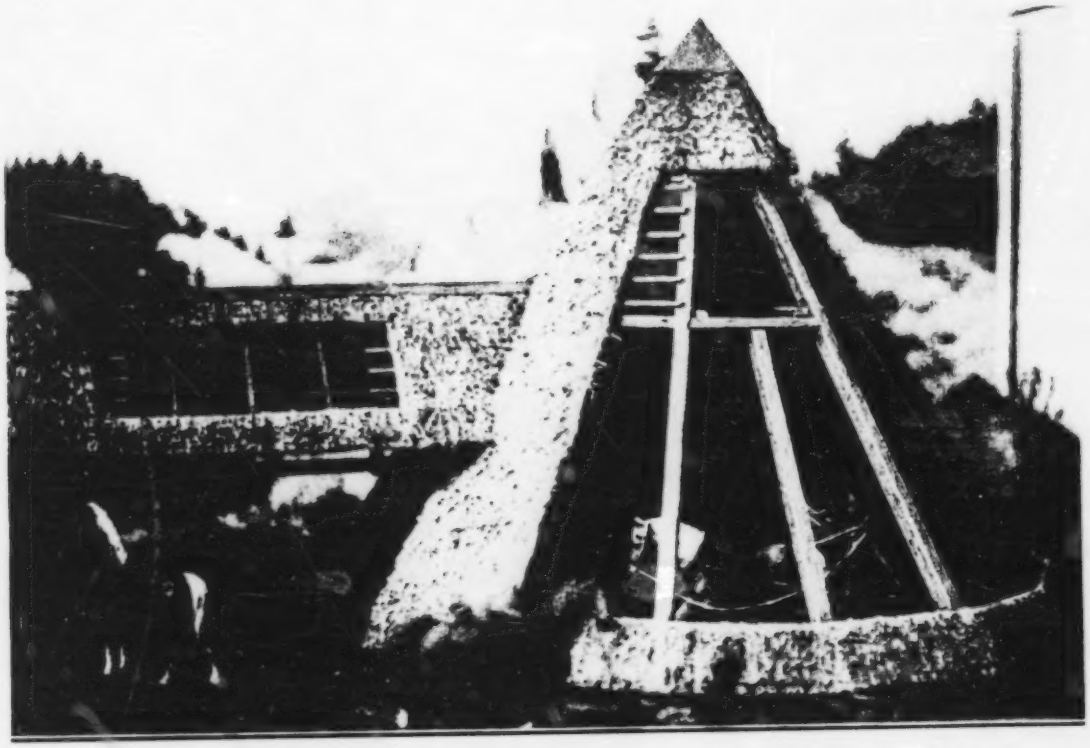

Figure 1

Model of a Horse Whim in Bohemia, Circa 1780
Deutsches Bergbau-Museum, Bochum, Germany

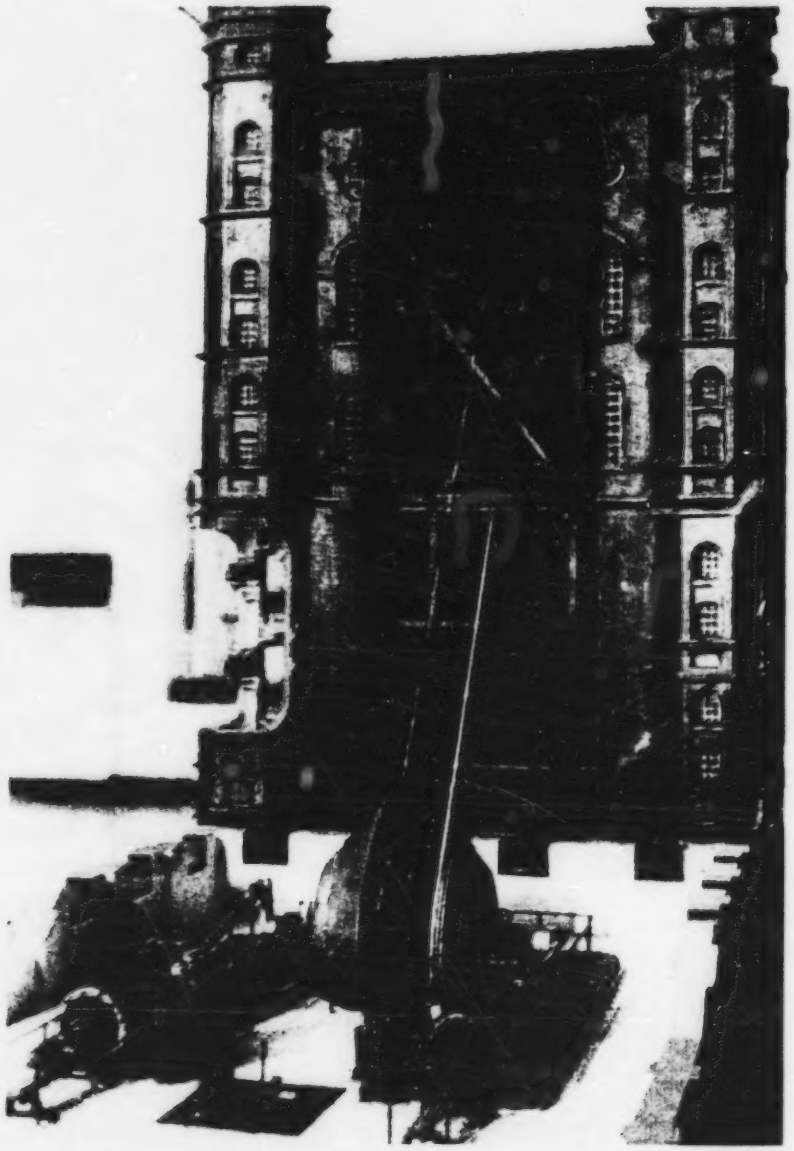

Figure 2

Model of the Fort Malakow Winder, Malakow-Turm, Circa 1850
Deutsches Bergbau-Museum, Bochum, Germany

Figure 3

An Example of Birdcaging
DMT Laboratories, Bochum, Germany

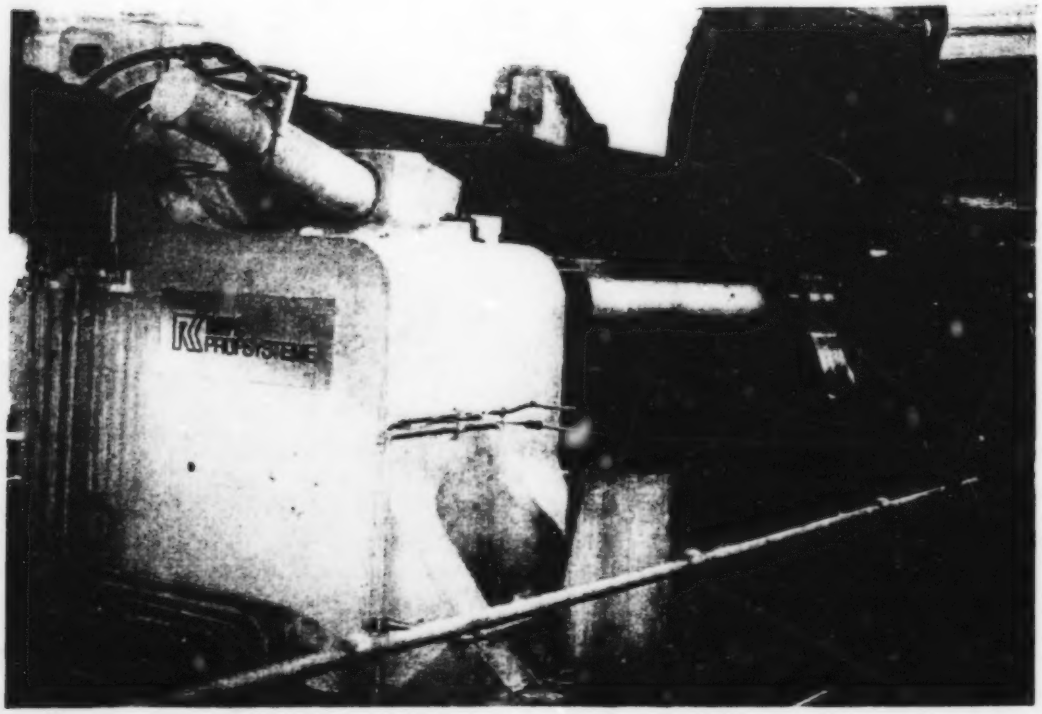

Figure 4

The Horizontal-Bed Testing Machine
CSIR/Miningtek, Cottesloe Campus, Johannesburg, South Africa

Figure 5

At CSIR/Miningtek's Cottesloe Laboratory
Johannesburg, South Africa

The number of samples indicates the volume of testing

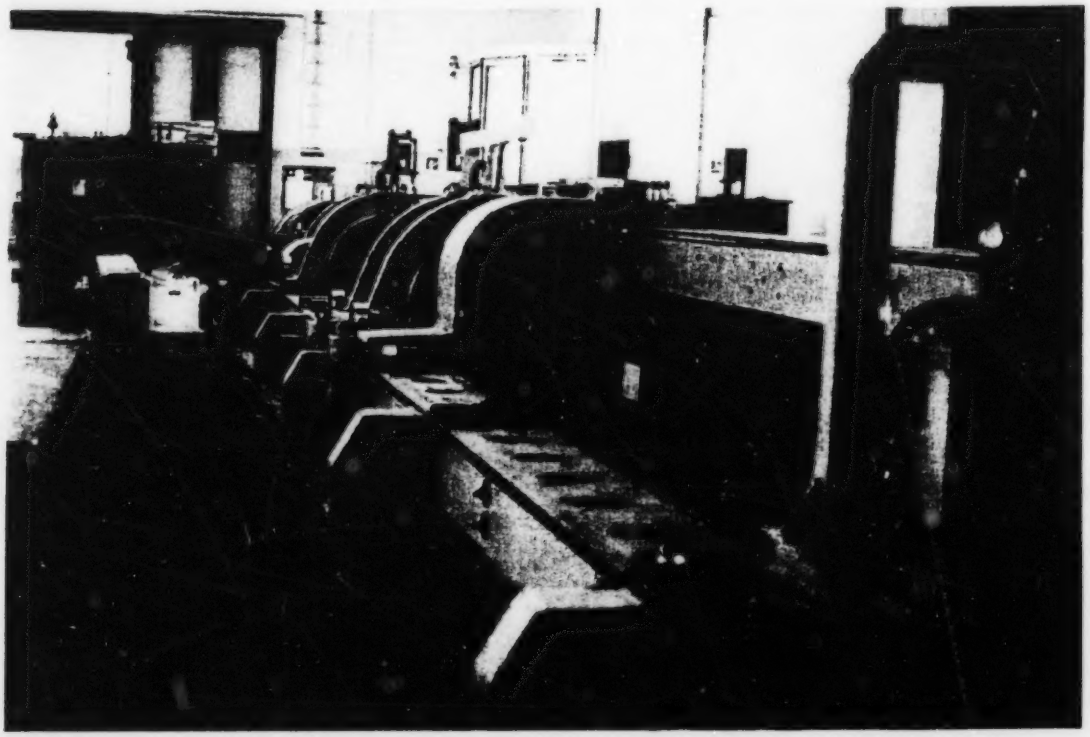

Figure 6

One of Two Horizontal-Bed Testing Machines
DMT Laboratories, Bochum, Germany

Note the bunker for the operator

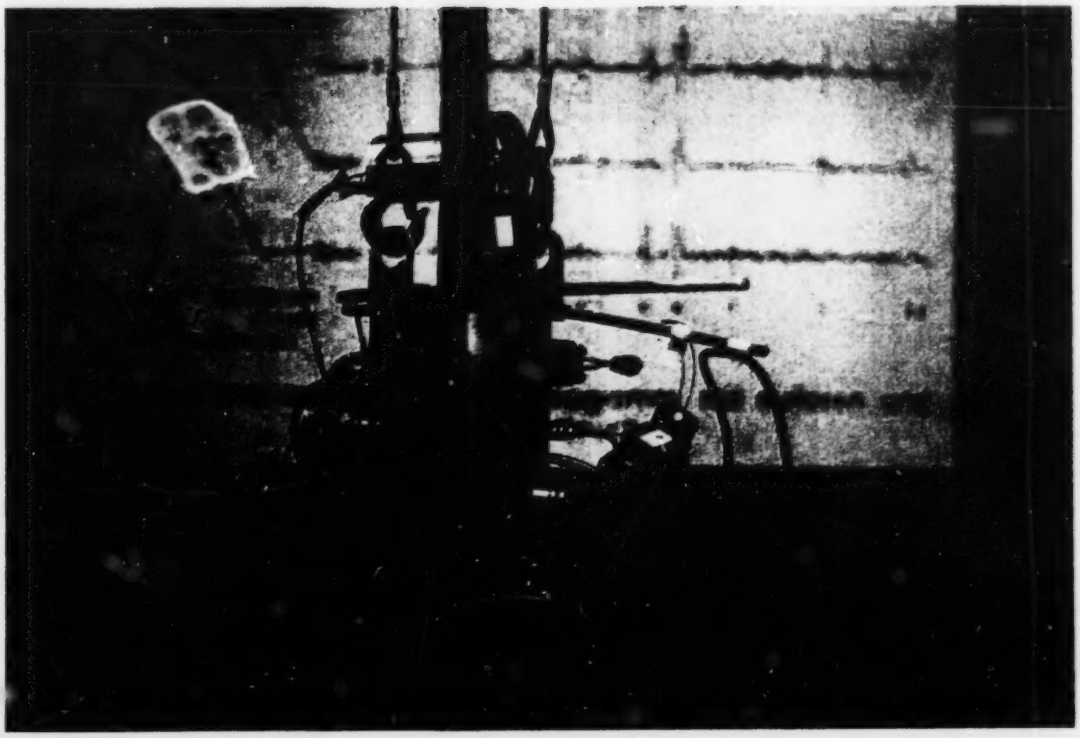

Figure 7

The Test Head at DMT, Bochum, Germany

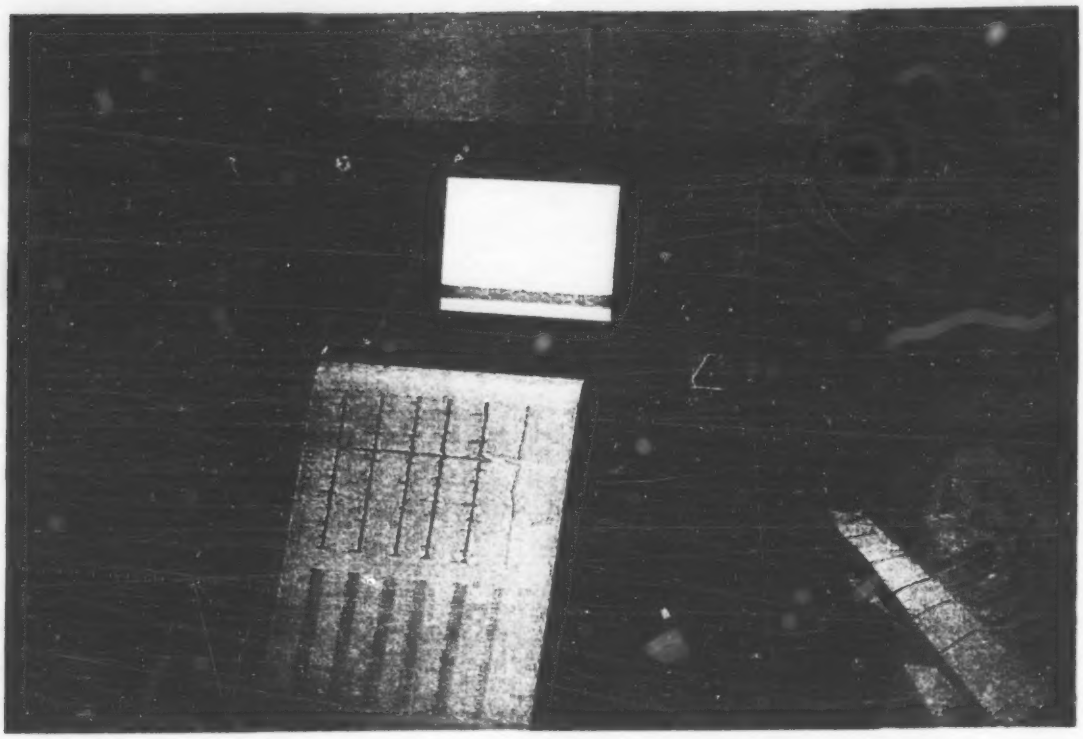

Figure 8

The DMT Instrument, Bochum, Germany

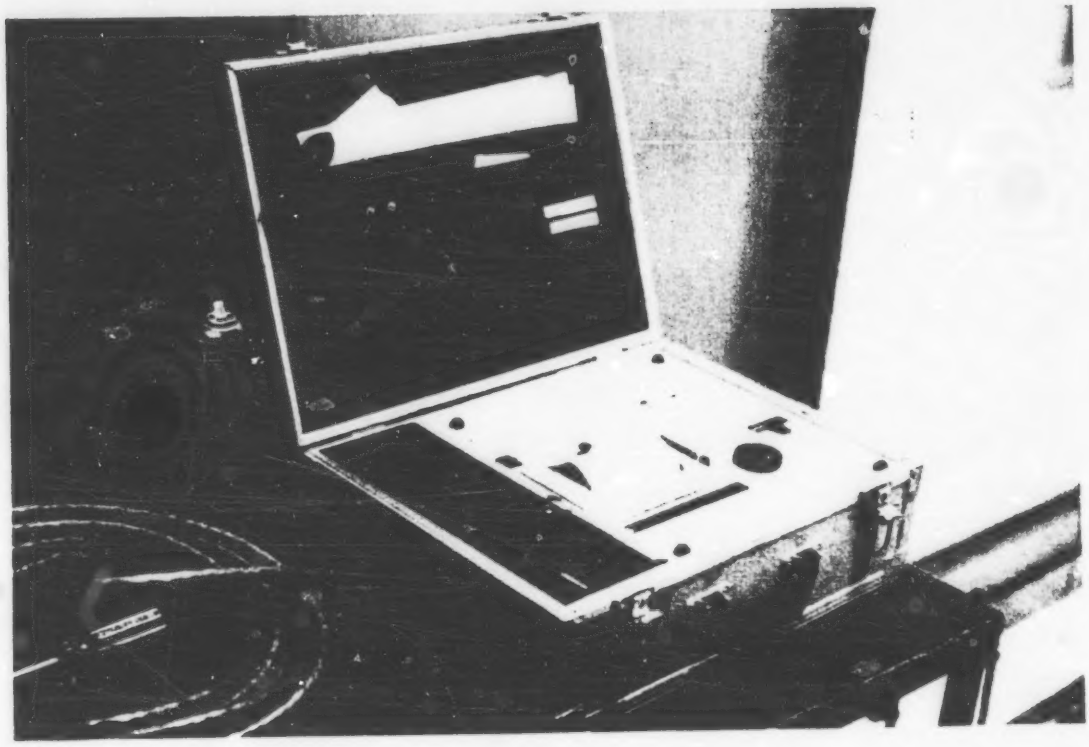

Figure 9

The Polish Instrument
University of Reading, Reading, United Kingdom

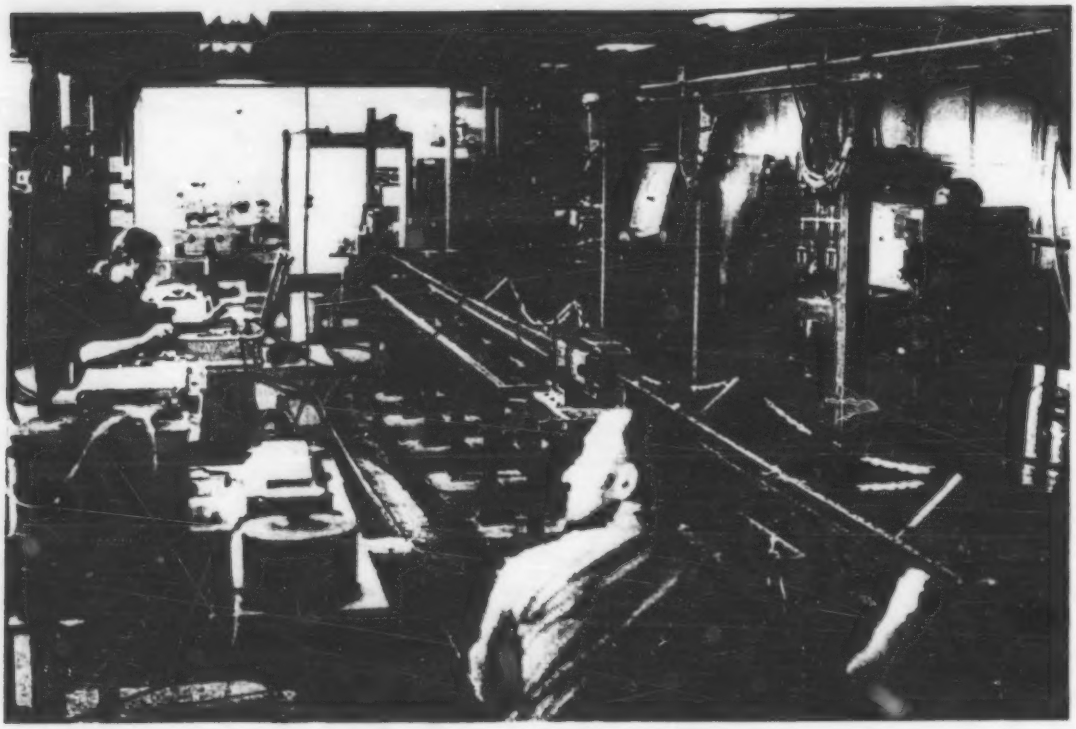

Figure 10

Testing the Polish System
University of Cracow, Cracow, Poland

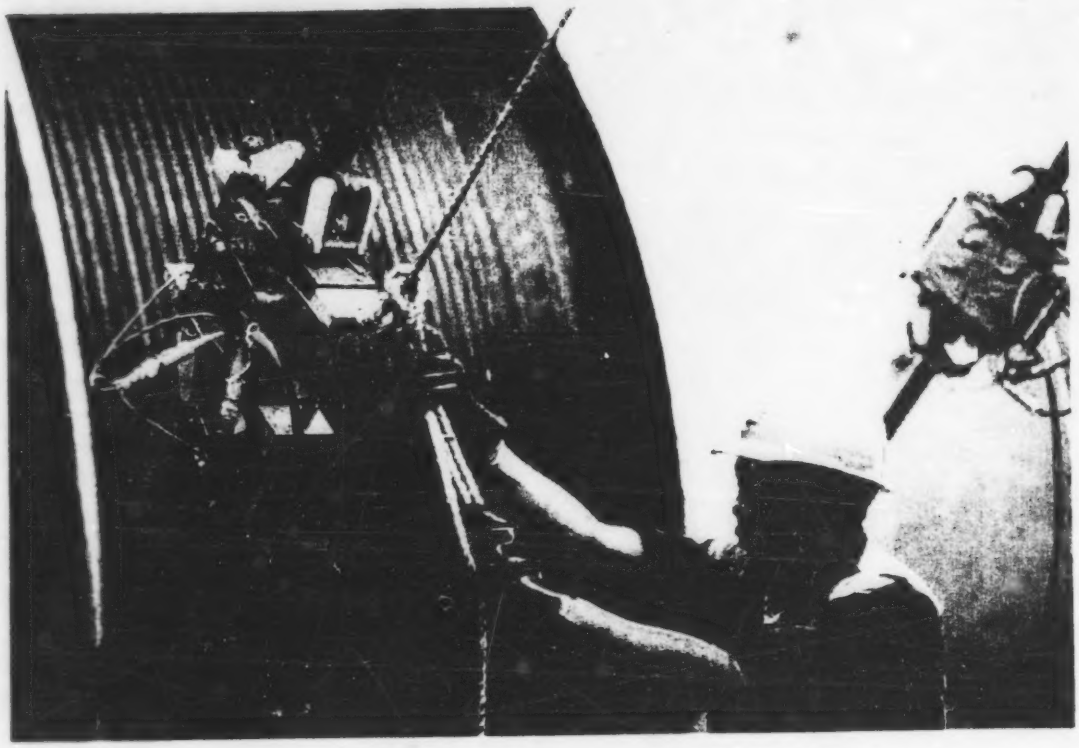

Figure 11

Testing of Wire Ropes
Elandsrand Mine, South Africa

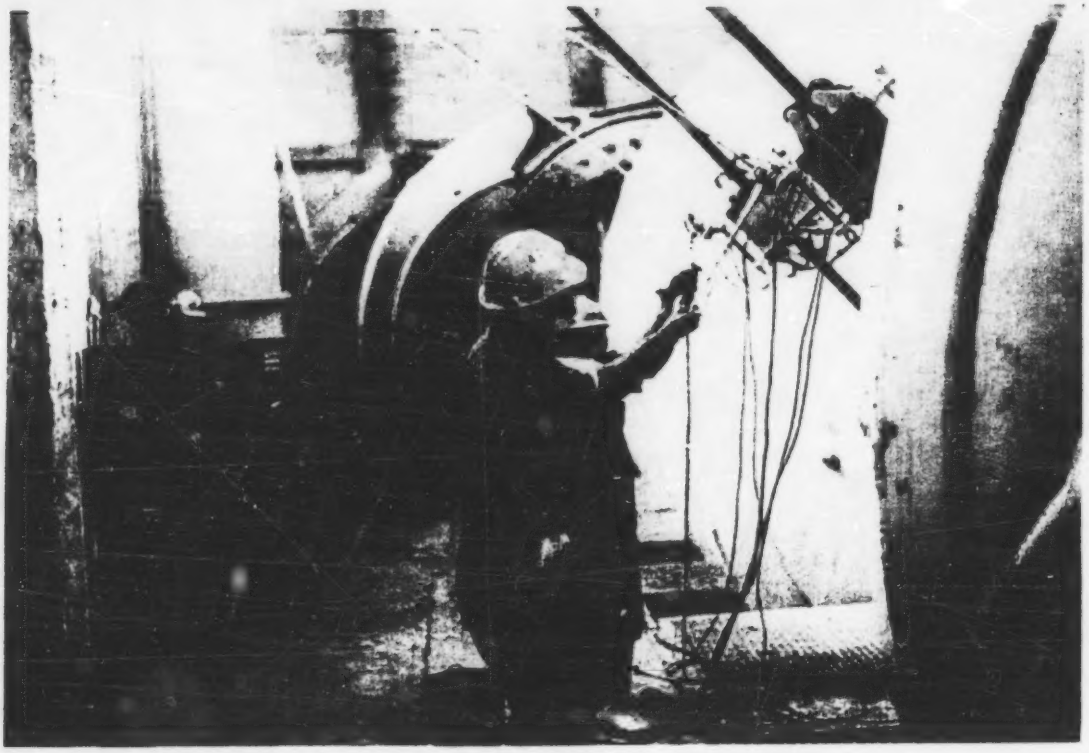

Figure 12

Testing of Wire Ropes on a BMR Drum
Elandsrand Mine, South Africa

Note the wire rope inspector, at the left, reading the instrument

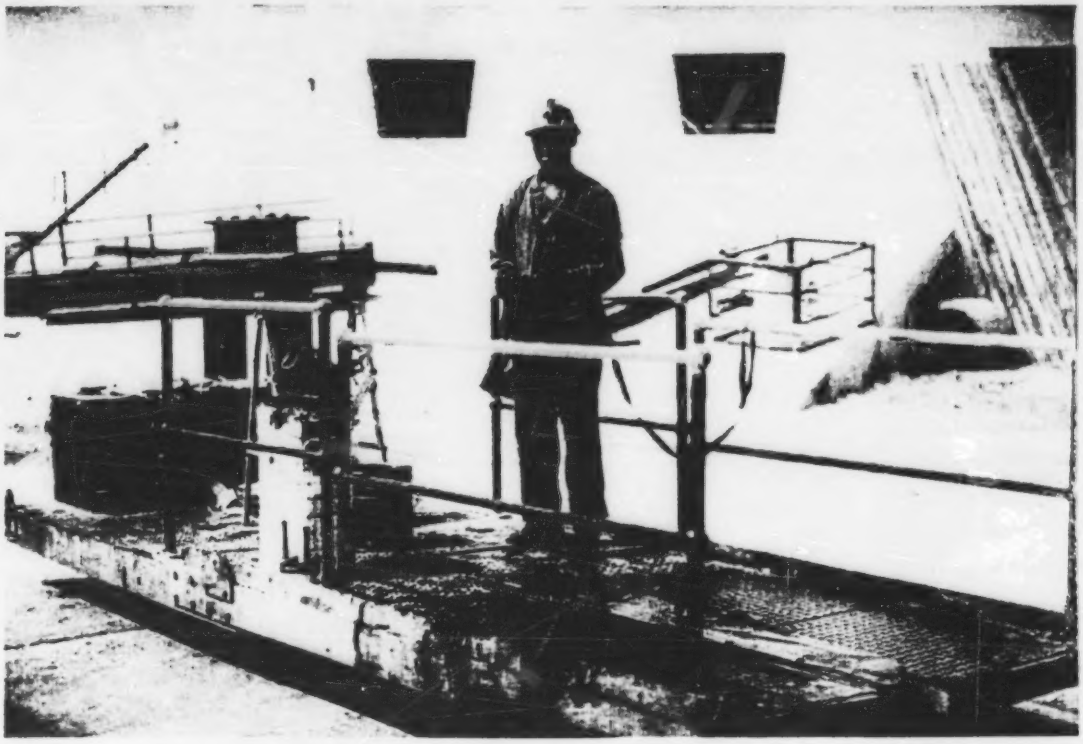

Figure 13

A Stage for Rope Inspection Constructed at the Moab Knotsong Mine
South Africa

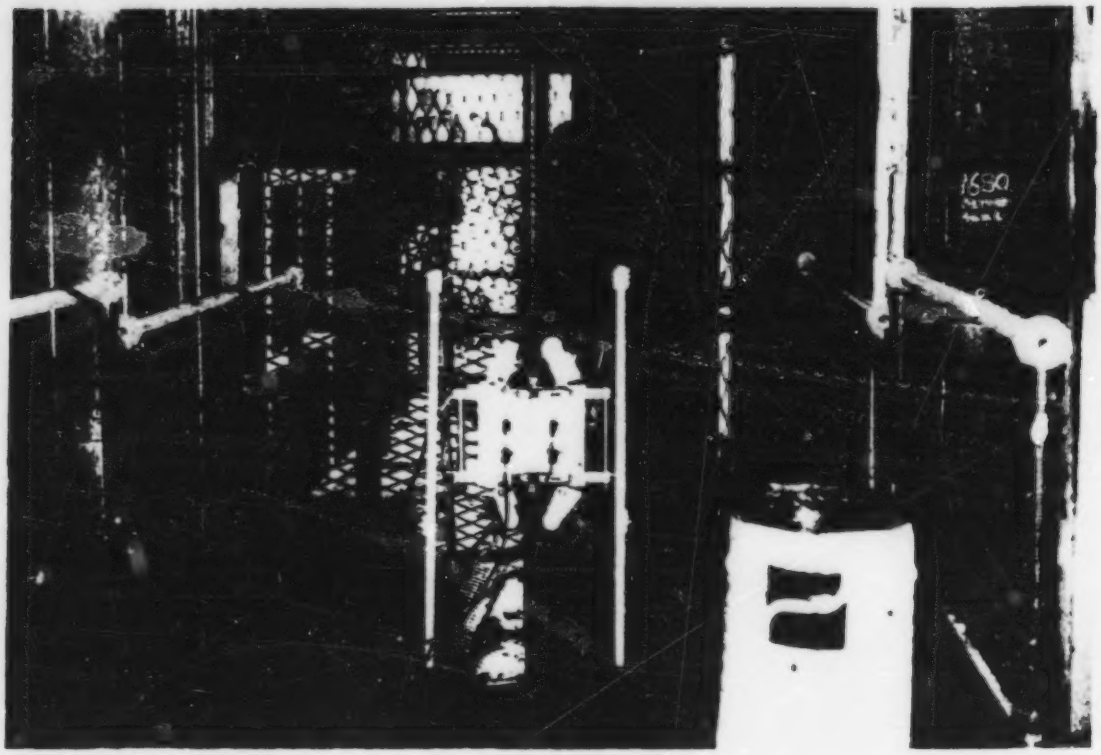

Figure 14

The Stage and Test Head in Place, Moab Knotsong Mine
South Africa

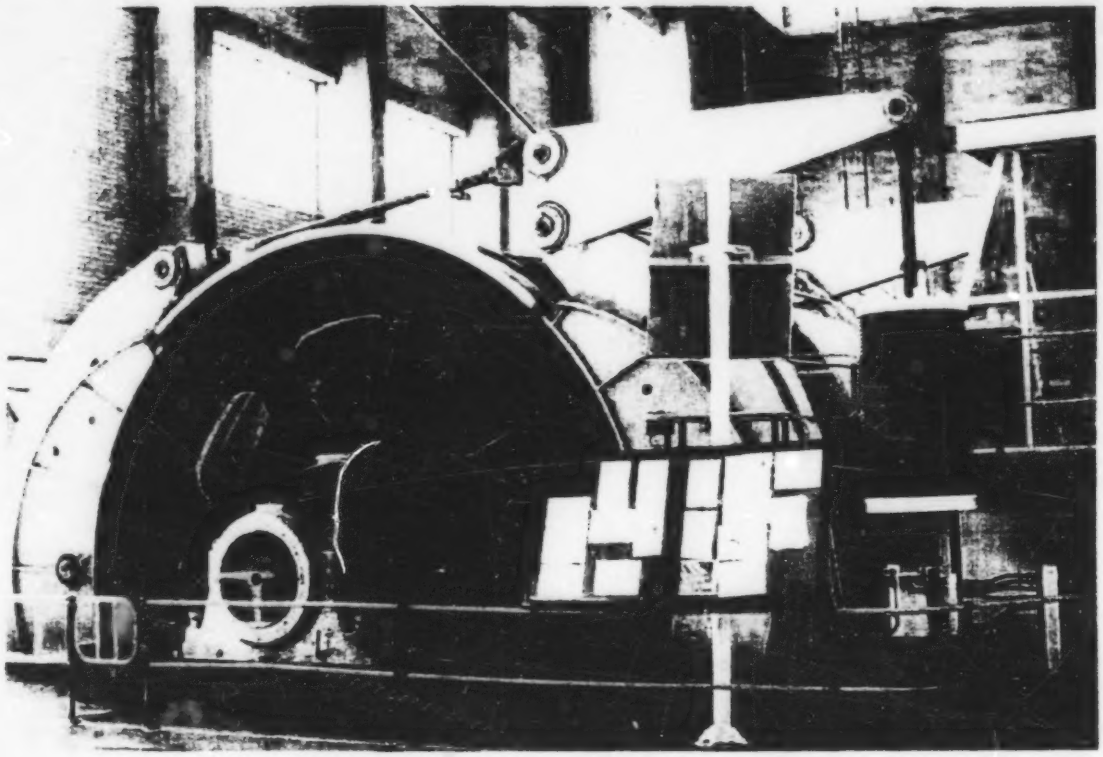

Figure 15

The Blair (BMR Winder) Hoist, Elandsrand Mine
South Africa

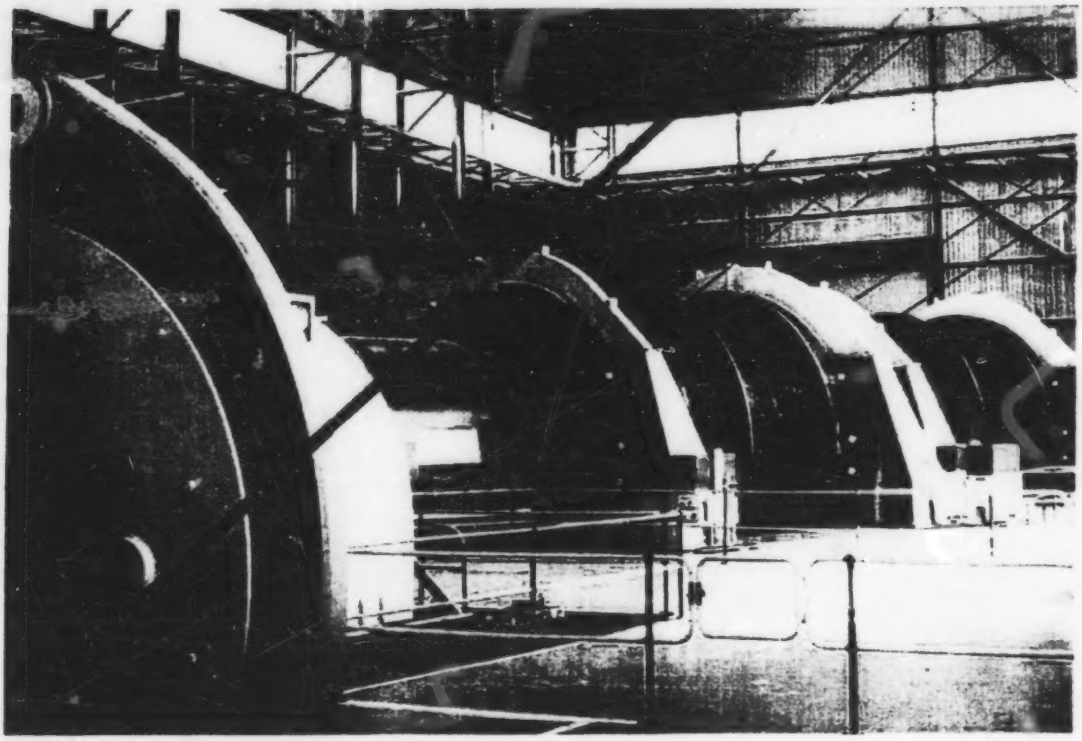

Figure 16

The Blair Hoist (BMR Winder), Moab Knotsong Mine
South Africa

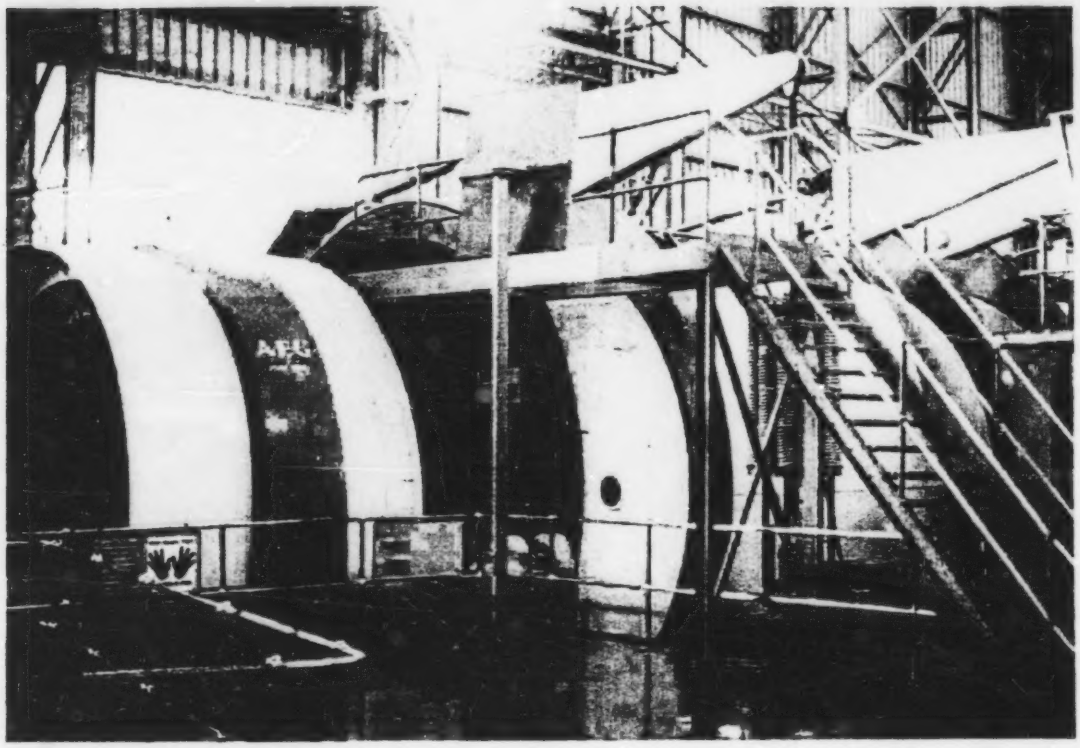

Figure 17

A Blair Hoist at Mponeng Mine
South Africa

Figure 18

The Headframe at Mponeng Mine, South Africa

Note the 12 ropes entering – 6 each, from the East and West Winders

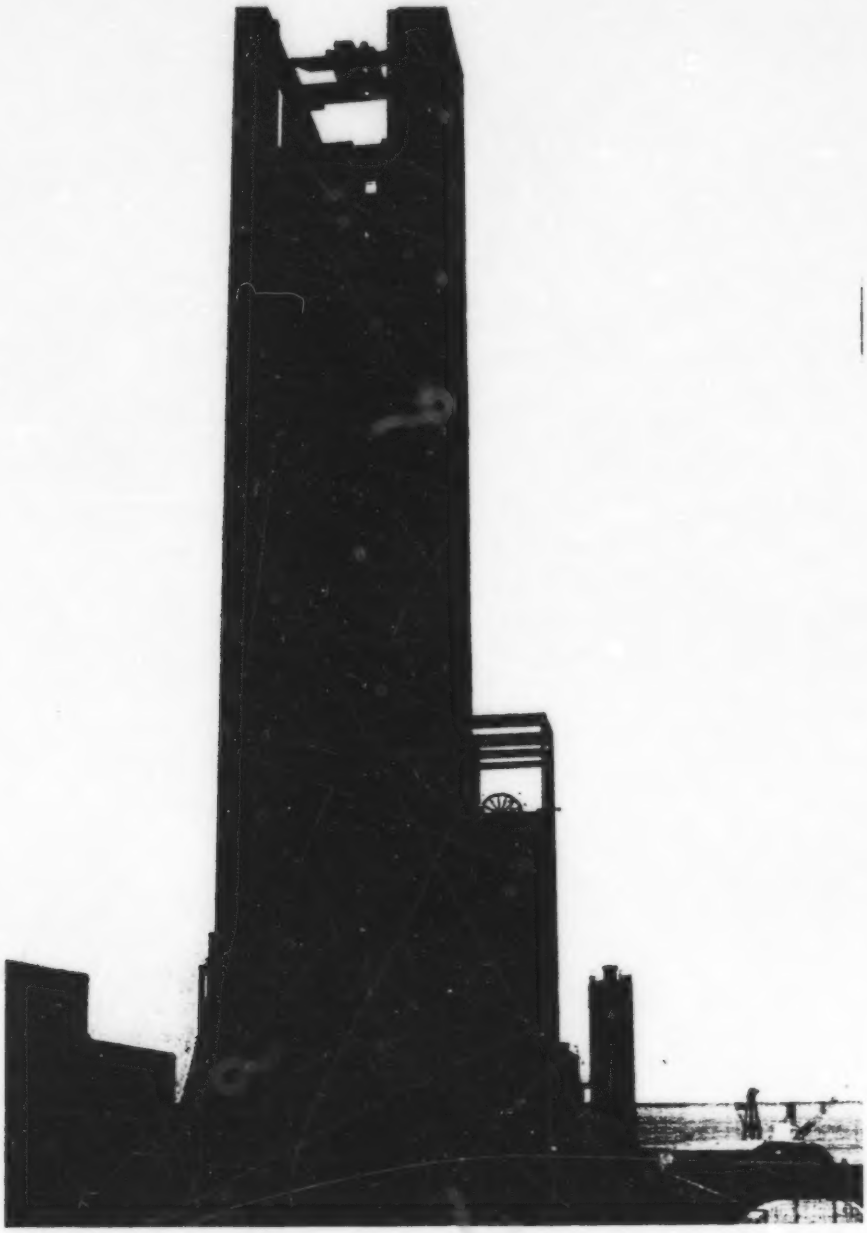

Figure 19

The Headframe at South Deep Mine, During Shaft Sinking
South Africa

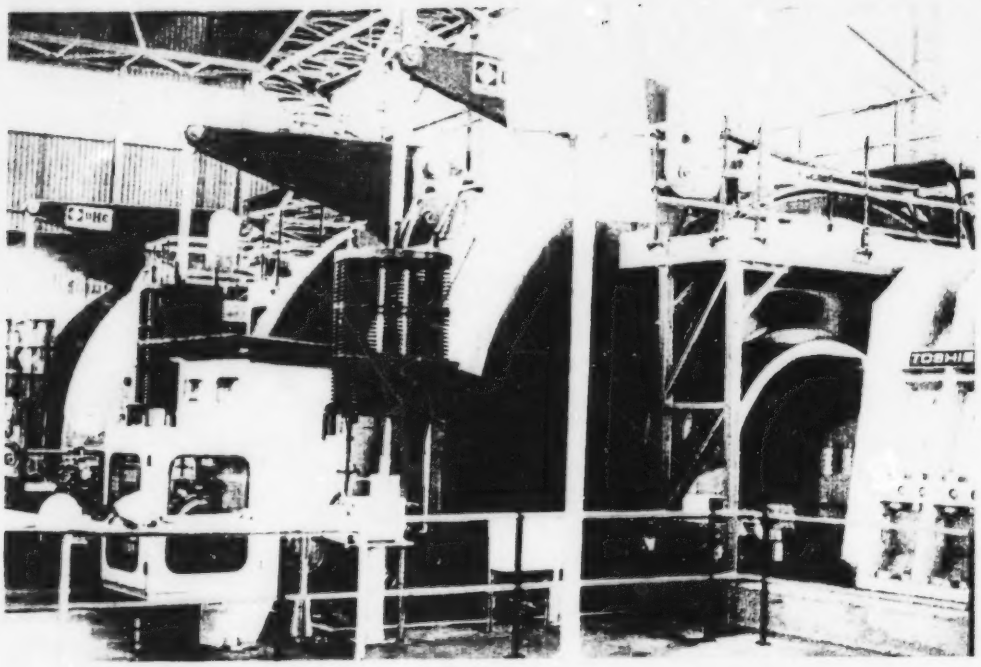

Figure 20

The Blair Winder at the South Deep Mine, South Africa

The most sophisticated mine hoist in the world in mid-2000